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ORBITER UTILIZATION AS AN ACRV

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Introduction

At the request of Level 1 Space Station Engineering Administrator Dr. Earle Huckins, the Langley SSFO performed an analysis of the utilization of a shuttle orbiter as an Assured Crew Return Vehicle (ACRV). Several candidate attach locations were studied. The impact on the flight dynamics characteristics were analyzed (e.g., torque equilibrium attitude, microgravity environment, attitude controllability requirements, and reboost fuel requirements). Qualitative assessments on viewing, clearance, docking and proximity operations, and radiator blockage were also noted. The feasibility of dual simultaneous docked orbiters was discussed. The baseline Permanently Manned Capability (PMC) and Assembly Complete (AC) configurations were considered, as well as selected modified hardware options, and a proposed new hardware option consisting of an *oblique* docking module design.

A summary of the results obtained was presented to Space Station Freedom Program Director Richard H. Kohrs on June 18, 1990. This TM consists of the presentation charts discussed with Mr. Kohrs, as well as accompanying facing pages.

LEVEL 1 SYSTEMS ENGINEERING ANALYSIS

Orbiter Utilization as an ACRV

Presented to

Richard H. Kohrs

Director, Space Station Freedom

June 18, 1990

Orbiter Utilization as an ACRV

CONTENTS

- Objective
- Ground Rules
- Assumptions
- Results
- Summary
- Unresolved Issues

Objective

Assuming that an orbiter could be qualified to serve long duration missions in the capacity as an Assured Crew Return Vehicle (ACRV), the objective of this preliminary analysis was to identify and examine candidate locations where an orbiter could be attached to Space Station *Freedom*. The impact on the flight characteristics were evaluated for the locations considered. Operational impacts were also addressed.

Orbiter Utilization as an ACRV

OBJECTIVE

- Identify and evaluate *Freedom* configuration options which can accommodate an Orbiter as an ACRV

Ground Rules

The primary ground rule constraint was that the attached ACRV orbiter shall be able to accommodate an emergency crew evacuation at all times. This necessarily implied that the orbiter must be IVA accessible at all times, and must be maintained in a ready state at all times. Although not a driver in the analysis performed for this study, it was assumed that the ACRV orbiter would require 8 kW of continuous power to maintain a continued readiness. However, station provided logistics or cooling would *not* be required.

In addition to the ACRV orbiter, the station must be able to accommodate a second "nominal" orbiter bringing crew, logistics, payloads, etc. It was assumed that this newly arriving orbiter would remain on the station to serve in the ACRV capacity, thus replacing the station based orbiter.

Orbiter Utilization as an ACRV

GROUND RULES

- Attached ACRV Orbiter Shall :
  - Accommodate emergency crew evacuation at all times
  - Be IVA accessible at all times
  - Require 8 kW continuous power
  - *Not* require Station provided logistics or cooling
- *Freedom* shall be capable of accommodating 2 attached Orbiters simultaneously
- Arriving Orbiter replaces station based ACRV Orbiter

Ground Rules (Continued)

Two station configurations were examined in this preliminary study: **P**ermanently **M**anned **C**onfiguration (PMC) and Assembly Complete (AC). Three hardware ground rules were considered:

Use current baseline hardware only
Use modified baseline hardware
Use newly developed hardware

Orbiter Utilization as an ACRV

GROUND RULES (continued)

- Preliminary study shall consider :
  - Two Station configurations
    - PMC – Permanently Manned Configuration
    - AC – Assembly Complete
  - Three Hardware approaches
    - Current baseline hardware configuration
    - Modified baseline hardware
    - New hardware development

Assumptions

Standard atmosphere assumptions were utilized in assessing flight characteristics of the station with attached orbiter(s). For the CMG control system sizing analysis, the so–called *design* atmosphere was utilized, assuming an altitude of 220 Nm. Since the control system must be able to maintain attitude before and after the arrival of the second orbiter, both one and two attached orbiter scenarios were analyzed.

A *nominal* atmosphere as suggested by P. Troutman/SSFO was utilized in determining the steady–state microgravity environments aboard *Freedom*. In particular, the solar flux was assumed to be 121, and the geomagnetic index was 22.6. For the purposes of micro–G determination, an altitude of 220 Nm was assumed. Assuming that micro–G experiments would not be performed while the second orbiter was attached, studies were done with an ACRV orbiter only.

Likewise, reboost would only occur with one attached ACRV orbiter. A 2σ atmosphere was assumed during the nominal times of flight (e.g., 1996 for PMC, and 2001 for AC). The reboost fuel requirements were determined in going from a lower altitude which was 150 Nm *plus* 90 days, to an upper altitude which provided an *additional* orbit lifetime of 45 days.

Orbiter Utilization as an ACRV

ASSUMPTIONS

- Controllability Studies (1 and 2 attached Orbiters)
  - Altitude : 220 Nm
  - Atmosphere : Design

- Microgravity Studies (1 attached Orbiter only)
  - Altitude : 220 Nm
  - Atmosphere : $\bar{f} = 121$, $A_p = 22.6$

- Orbit Lifetime & Reboost Studies (1 attached Orbiter only)
  - Altitude : Lower = 150 Nm + 90 days
Upper = Lower + 45 days
  - Atmosphere : 2σ (AC : 2001 , PMC : 1996)

Reference Configuration Studied

To serve as a **reference**, both the Permanently Manned Configuration (PMC), and the Assembly Complete (AC) configurations were examined both with and without an orbiter attached at the *nominal* docking location on the forward port resource node.

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REFERENCE CONFIGURATIONS STUDIED

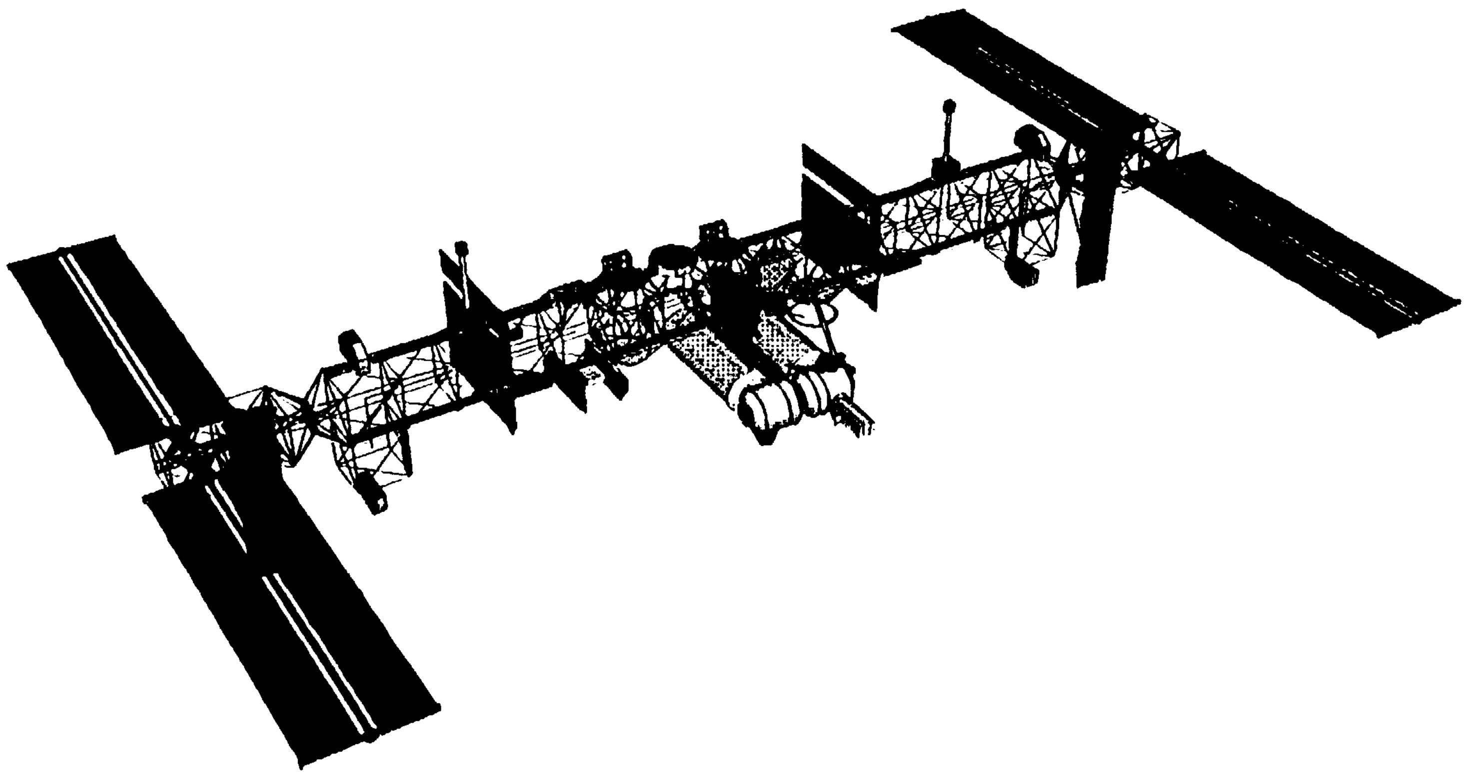
- PMC
  - With Orbiter
  - Without Orbiter
- AC
  - With Orbiter
  - Without Orbiter

Permanently Manned Capability

This is the baseline configuration that occurs after the thirteenth orbiter assembly flight (i.e., the first logistics flight, L-1, which occurs right after the tenth mission build flight, MB-10). The baseline PMC station is included in this study as a reference with which to compare the configurations that include an orbiter as an ACRV.

pmc

Permanently Manned Capability (PMC)



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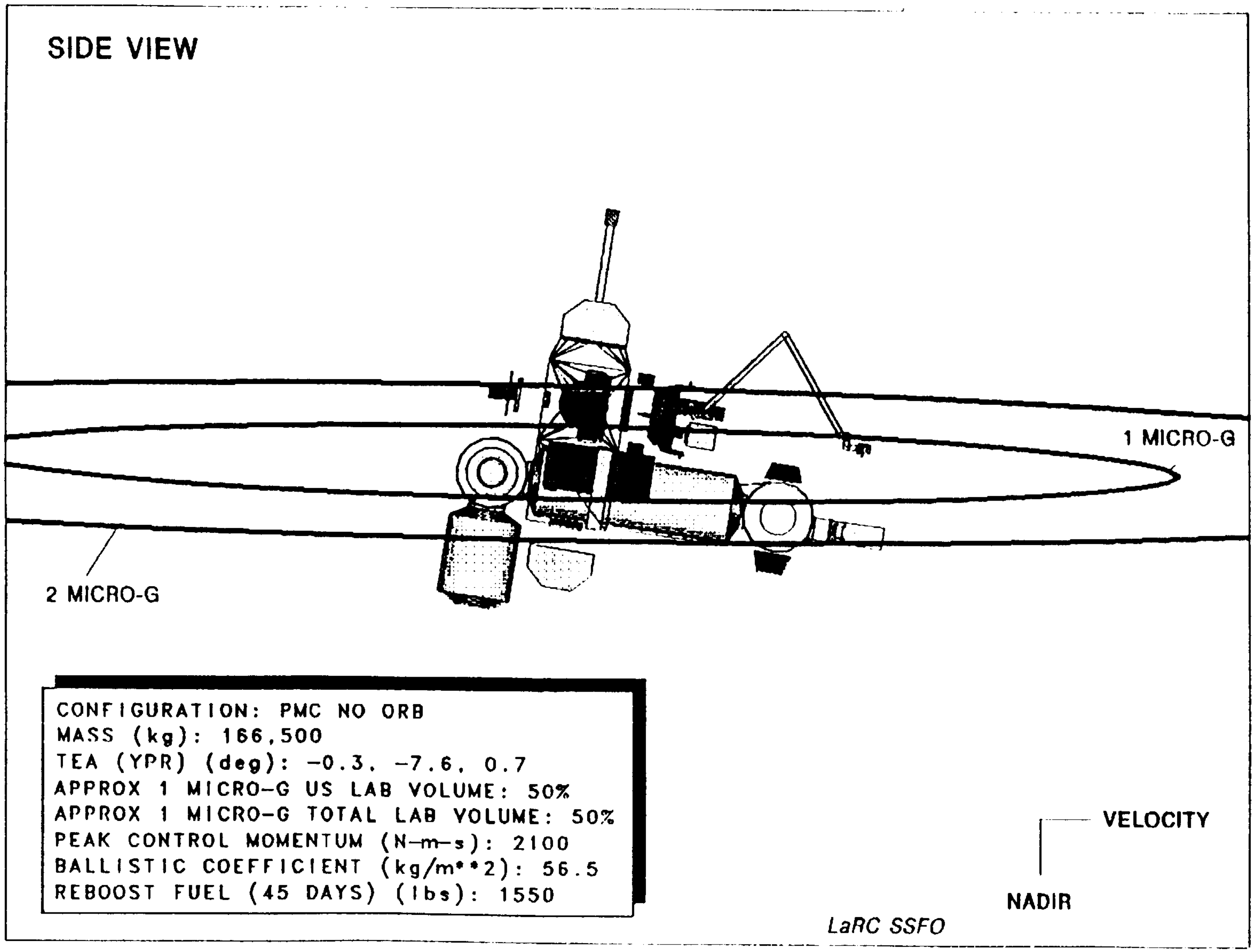
PMC Baseline-Steady State Microgravity Contours

The envelopes in which the steady state microgravity is maintained within one and two μGs are shown for the baseline PMC configuration. The view is from the starboard side and the station is oriented to its pitch Torque Equilibrium Attitude (TEA) of –7.6 degrees. Note that only approximately 50% of the pressurized lab volume falls within the one μG contour.

pmc micro-g

PMC BASELINE

STEADY STATE MICROGRAVITY CONTOURS



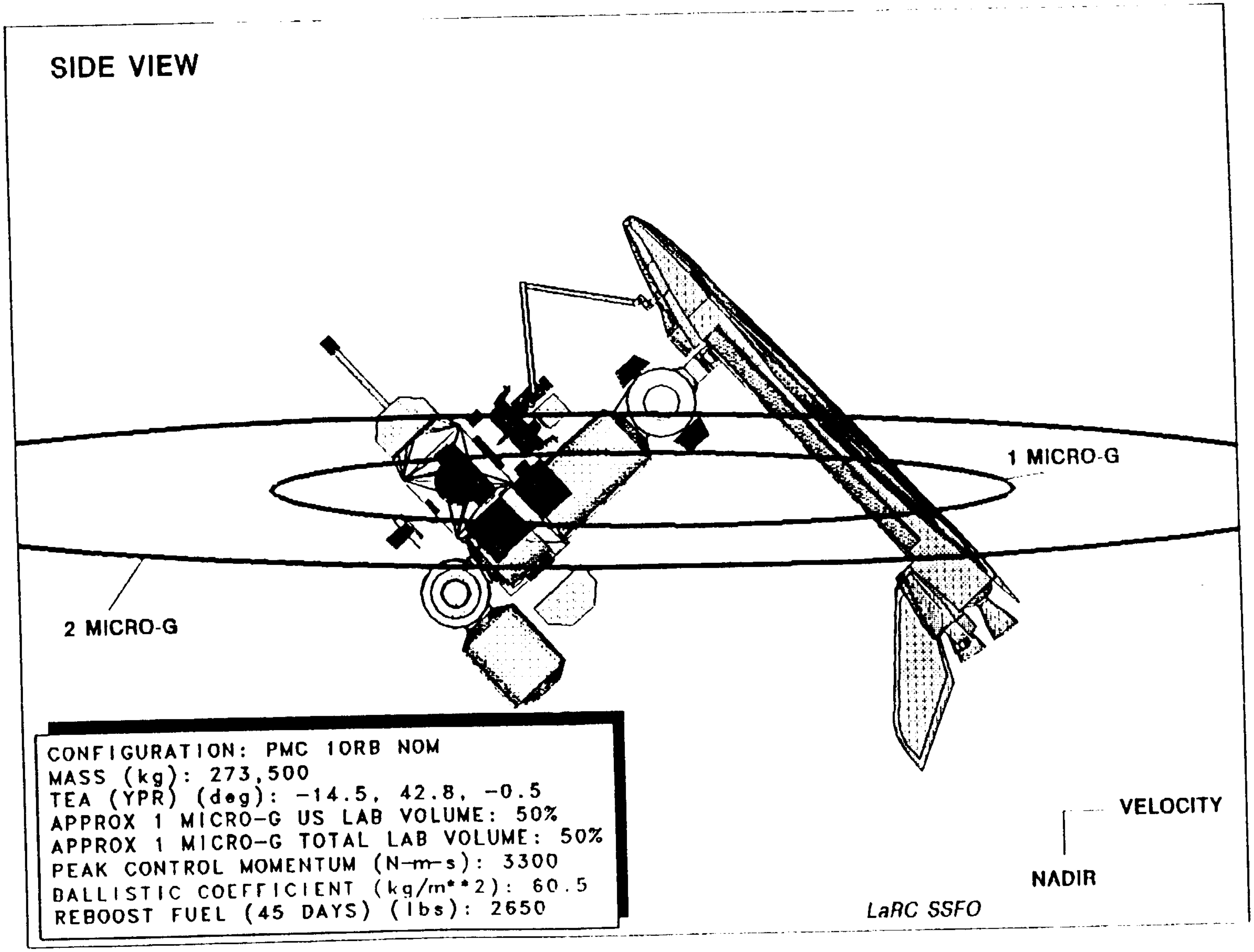
PMC Baseline-Steady State Microgravity Contours (with Orbiter Berthed)

This is the baseline PMC station with a resupply orbiter (not an ACRV orbiter) berthed to the port node docking mast. The contours show the envelopes of the one and two microgravity environments. The view is from the starboard side and the station is oriented to its pitch TEA of 42.8 degrees. Although oriented differently from the baseline PMC configuration (no orbiter attached), there is still approximately 50% of the pressurized lab volume within the one μG volume.

pmc&orb micro-g

PMC BASELINE

STEADY STATE MICROGRAVITY CONTOURS

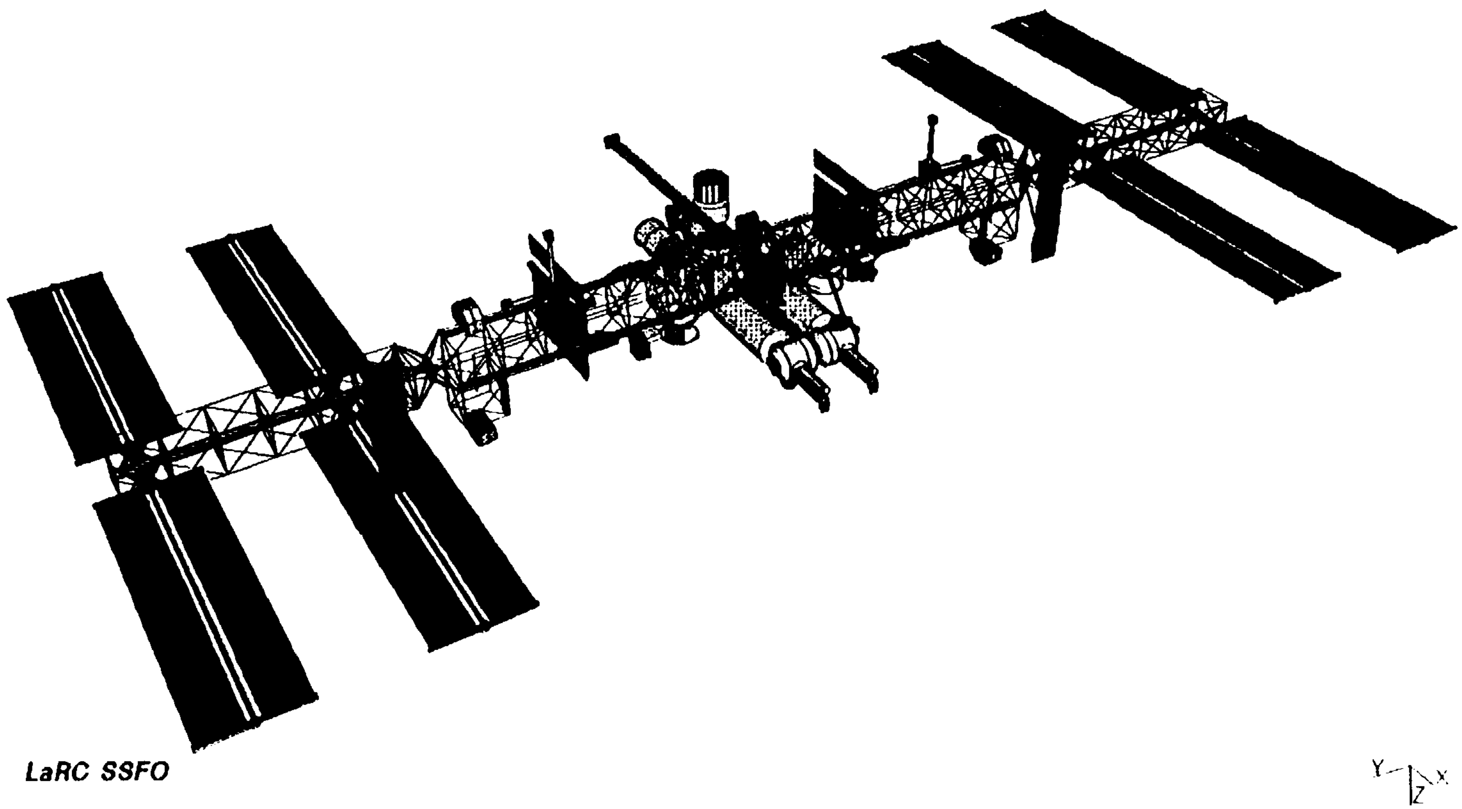


Assembly Complete

This is the baseline assembly complete Space Station Freedom configuration. The baseline AC station is included in this study as a reference with which to compare the configurations that include an orbiter as an ACRV.

ac

Assembly Complete (AC)



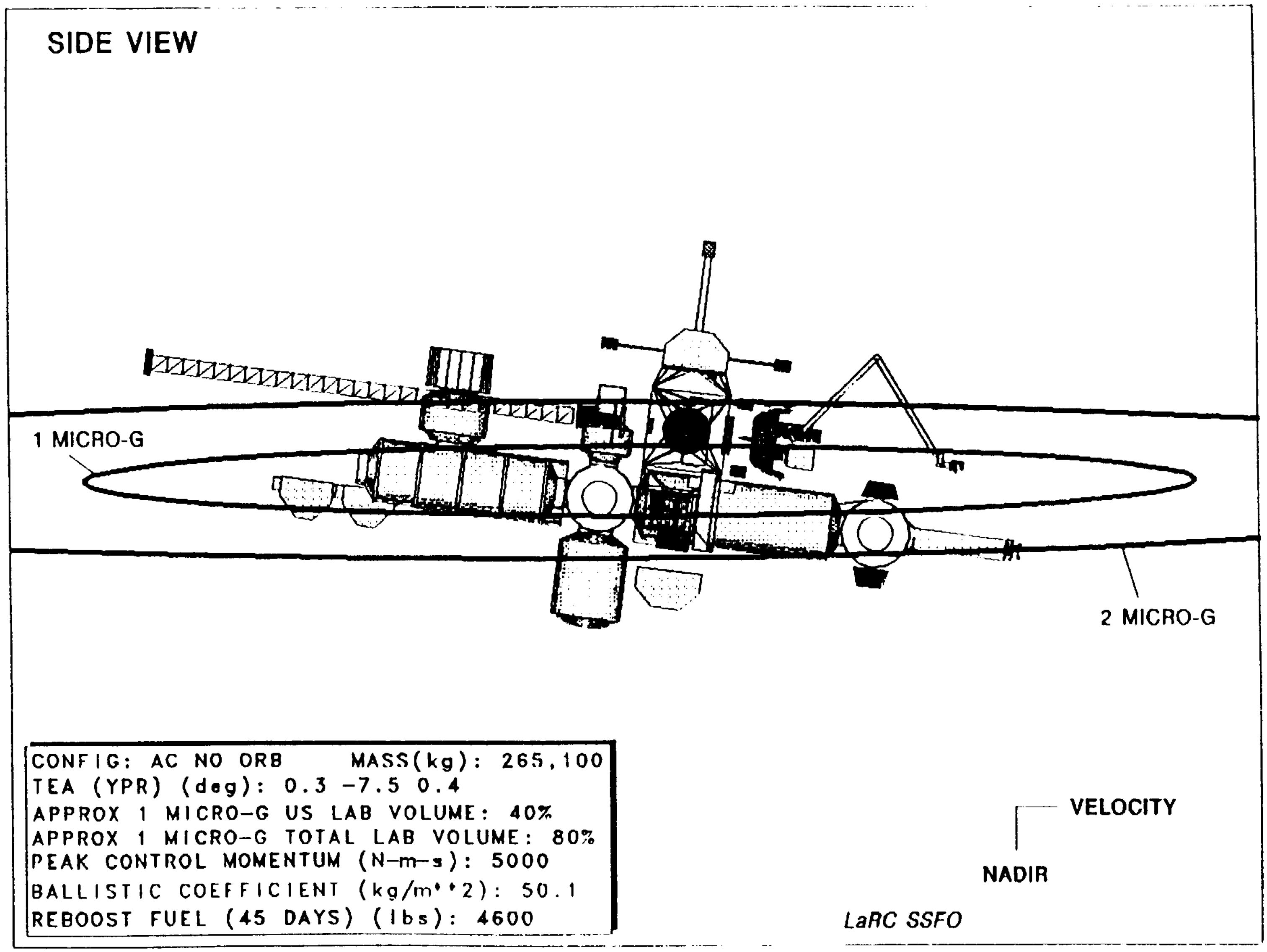
LaRC SSFO

Assembly Complete Baseline–Steady State Microgravity Contours

The envelopes in which the steady state microgravity is maintained within one and two μGs are shown for the baseline AC configuration. The view is from the starboard side and the station is oriented to its pitch TEA of -7.5 degrees. Note that the international labs lie almost entirely within the one μG volume, compared to only approximately 40% of the US lab volume.

ASSEMBLY COMPLETE BASELINE

STEADY STATE MICROGRAVITY CONTOURS



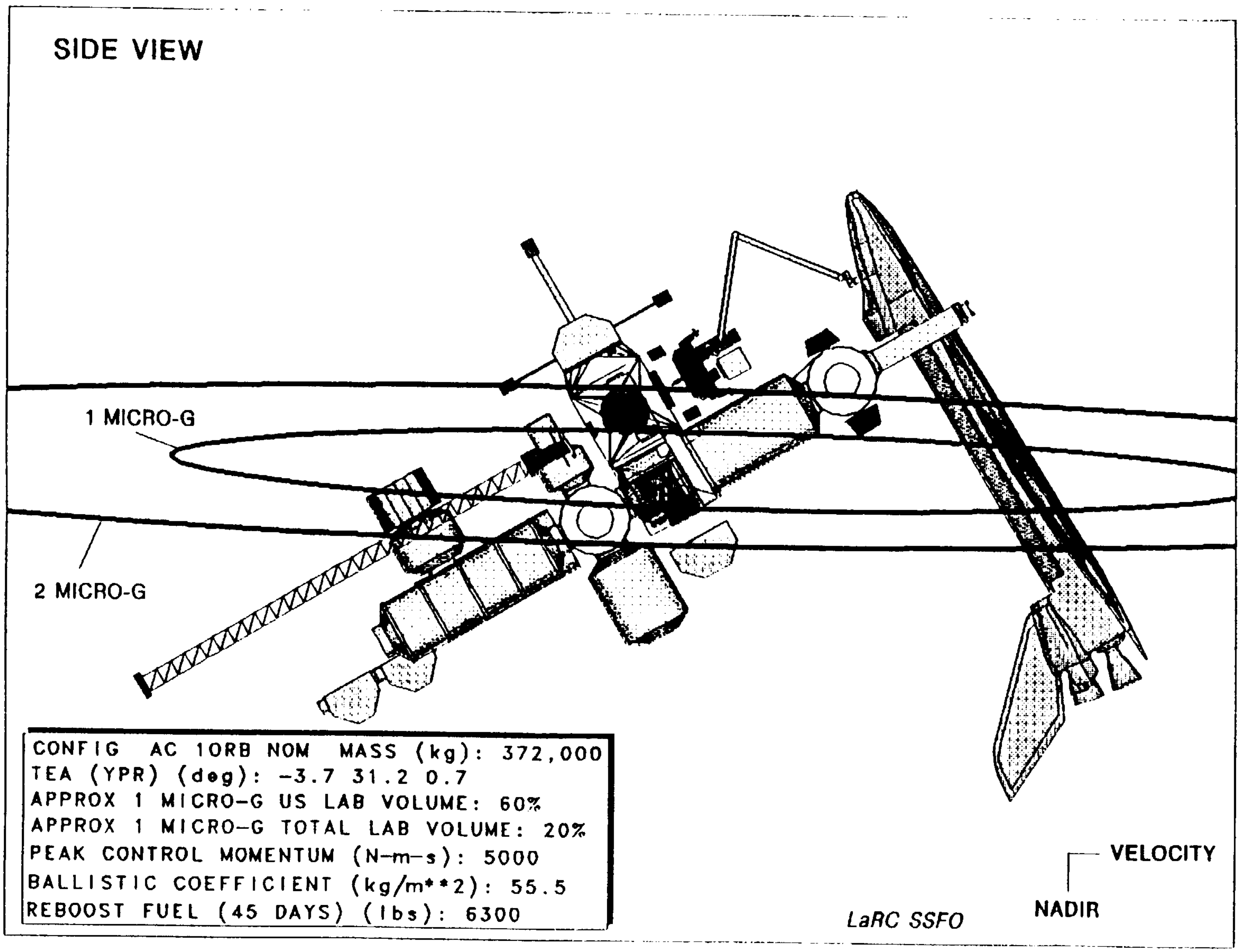
Assembly Complete Baseline–Steady State Microgravity Contours (with Orbiter Berthed)

This is the baseline AC station with a resupply orbiter (not an ACRV orbiter) berthed to the port node docking mast. The contours show the envelopes of the one and two microgravity environments. The view is from the starboard side and the station is oriented to its pitch TEA of 31.2 degrees. Note that approximately 60% of the US lab volume is contained within the one μG contour, but the international labs are almost entirely outside the one μG contour.

ac&orb micro–g

ASSEMBLY COMPLETE BASELINE

STEADY STATE MICROGRAVITY CONTOURS



Current Baseline Hardware Approach

Using current baseline station hardware only, two optional ACRV accommodation configurations were considered. The *nominal* orbiter was assumed to be on the forward port resource node, in a tail-down orientation. In option 1–A, the ACRV orbiter was assumed to be located on the forward *starboard* resource node, also in a tail-down orientation. Option 1–B was the same as 1–A, except that the ACRV orbiter was orientated in a *tail-up* attitude.

Orbiter Utilization as an ACRV

Current Baseline Hardware Approach

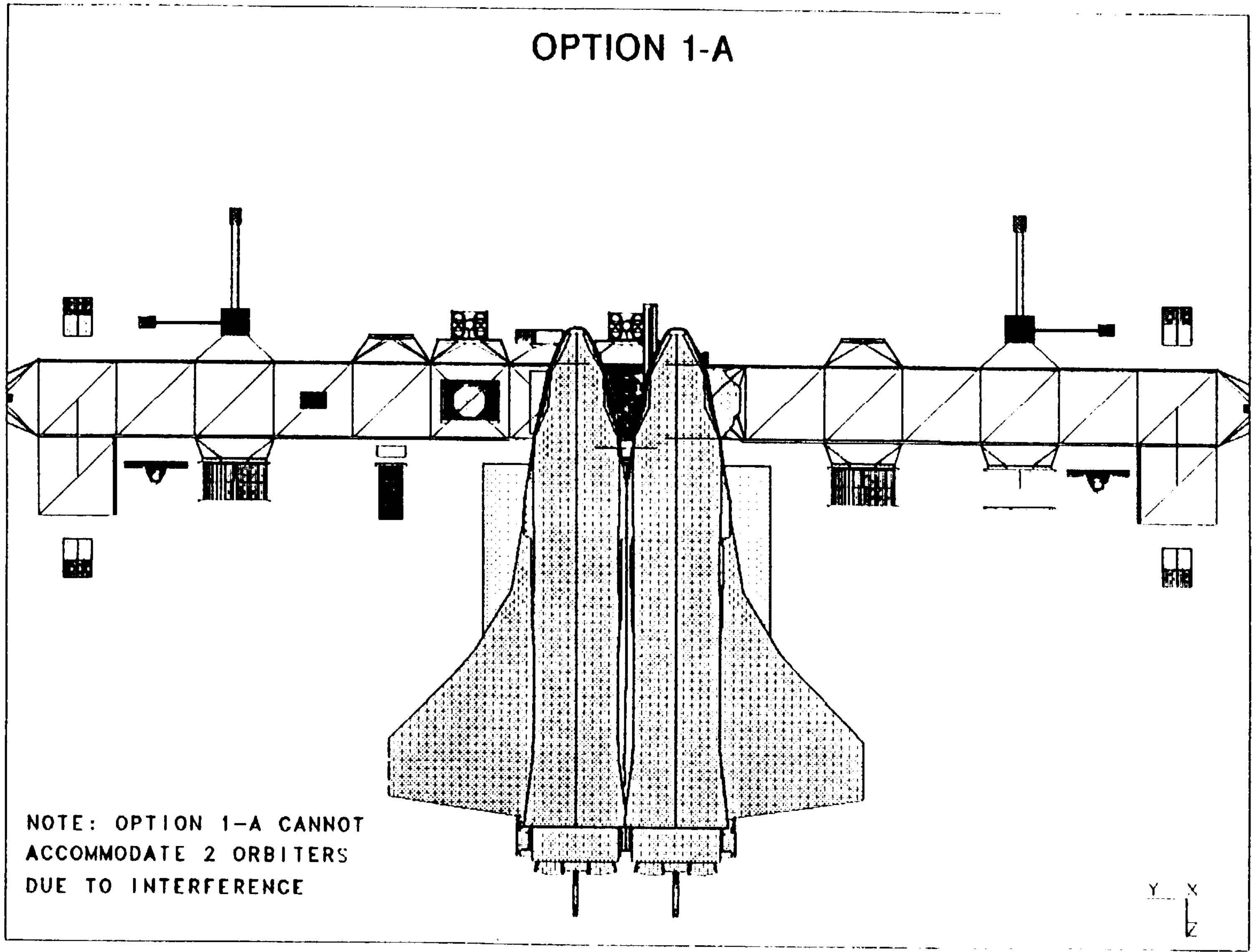
- Both docking masts on front resource nodes ; nominal Orbiter on port node – forward facing, tail down. Two locations considered for ACRV Orbiter :
  - **Option 1–A** : ACRV Orbiter on starboard node – forward (tail down)
  - **Option 1–B** : ACRV Orbiter on starboard node – forward (tail up)

Assembly Complete Baseline with Two Orbiters Berthed on Front Nodes (Option 1-A)

In this configuration, two orbiters are berthed in a nose-up attitude to the docking masts on the two forward nodes of the baseline station. There was obvious interference between the two orbiters which made the option physically impossible. Therefore, no further analysis was performed on this option.

opt1-a front

ASSEMBLY COMPLETE BASELINE
WITH TWO ORBITERS BERTHED ON FRONT NODES

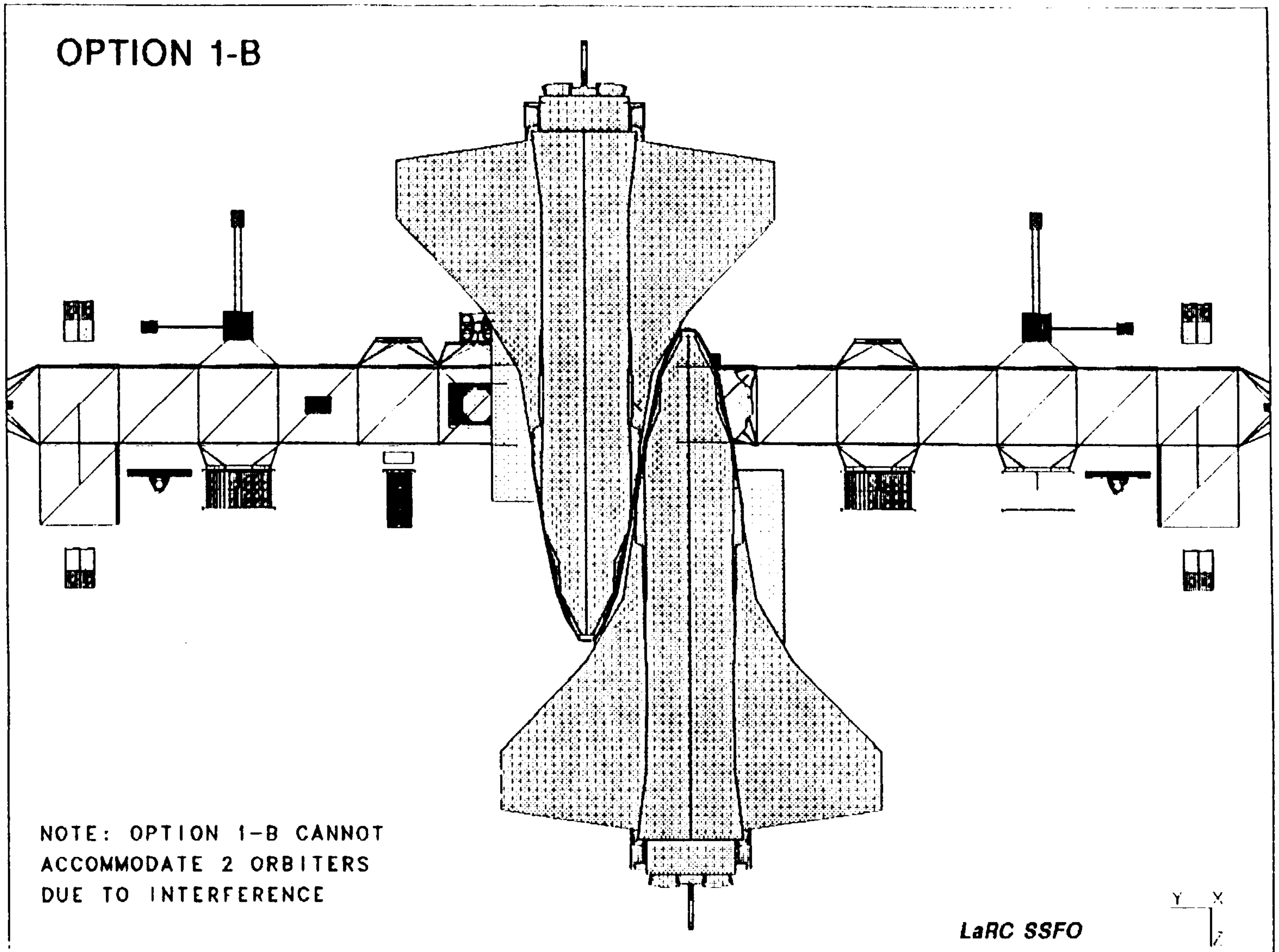


Assembly Complete Baseline with Two Orbiters Berthed on Front Nodes (Option 1-B)

In this configuration, two orbiters are berthed in a one nose-up, one nose-down attitude to the docking masts on the two forward nodes of the baseline station. Again, there was obvious interference between the two orbiters and no further analysis was done on this option.

opt1-b front

ASSEMBLY COMPLETE BASELINE WITH TWO ORBITERS BERTHED ON FRONT NODES



Modified Hardware Approach

Under the modified hardware approach, six options were considered, namely, options 2 through 7. Modified hardware options include relocation of docking mechanisms, and/or minor changes to existing baseline hardware.

Option 2 relocated the starboard node docking mechanism from the front of the resource node to the end port of the node. In particular, option 2–A oriented the ACRV orbiter in a tail–down configuration, while option 2–B was tail–up.

For both options 2–A and 2–B, the nominal orbiter was assumed to be located on the forward port resource node.

Orbiter Utilization as an ACRV

Modified Hardware Approach

- Nominal Orbiter on front port resource node – facing forward, tail down. Six modified hardware locations considered for ACRV Orbiter :
  - **Option 2 :** Move starboard node docking mechanism to end port
    - **A.** ACRV Orbiter tail down
    - **B.** ACRV Orbiter tail up
  - **Option 3 :** Replace baseline resource nodes with *extended* resource nodes ; ACRV Orbiter on starboard node, forward, tail up
  - **Option 4 :** ACRV Orbiter attached to *additional* starboard node, forward, tail up
  - **Option 5 :** ACRV Orbiter attached to *additional extended* starboard node, forward, tail up
  - **Option 6 :** ACRV Orbiter attached to modified logistics module, nose forward
  - **Option 7 :** ACRV Orbiter attached to modified ESA module, nose forward

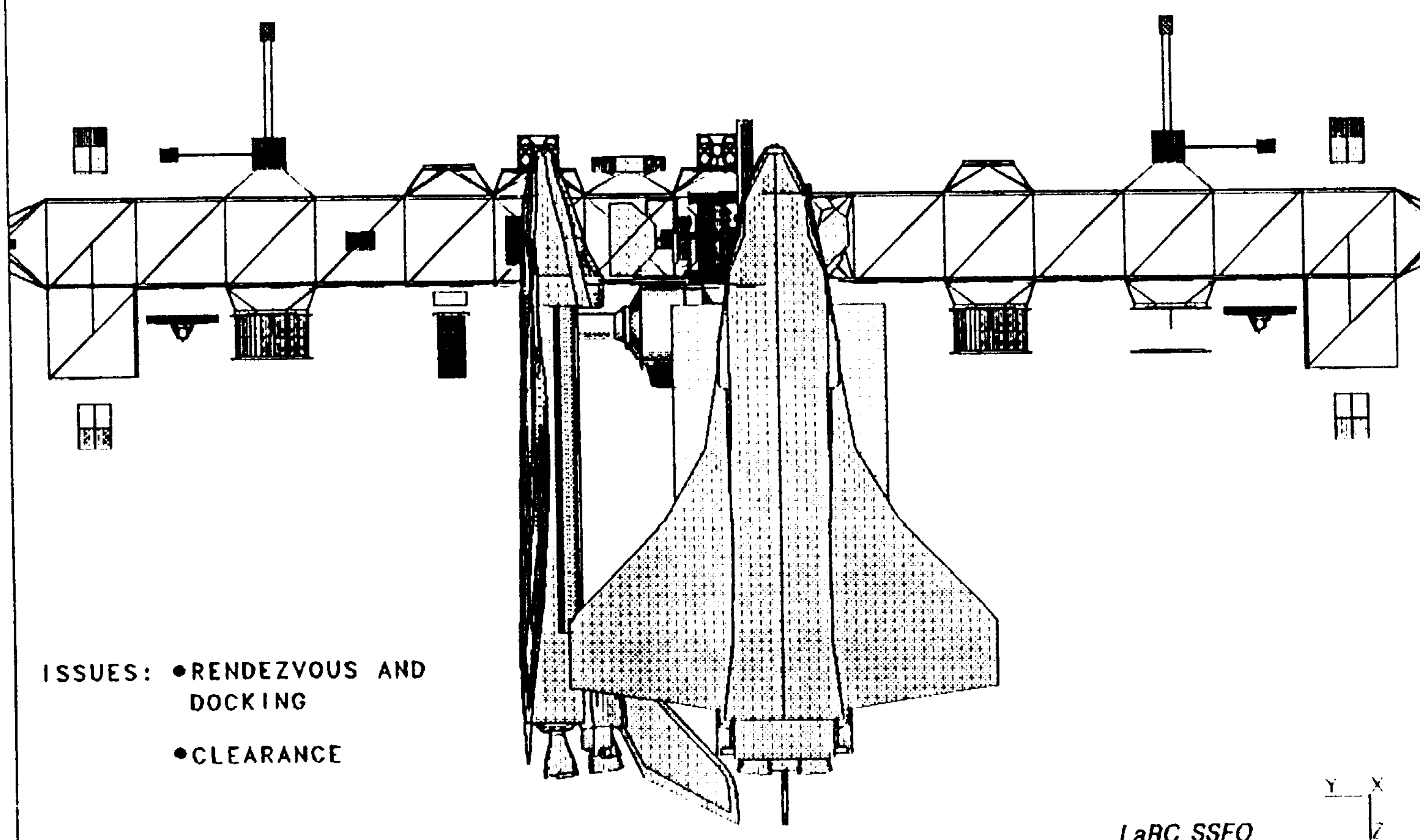
Assembly Complete with Starboard Docking Mast Moved to Side of Forward Starboard Node (Option 2-A) - Front View

This option studied the possibility of having the ACRV orbiter berthed to the side of the starboard node. This configuration was physically possible (there was no interference), but other problems removed it from consideration as a viable option. First, there would be a major problem with rendezvous and docking of the ACRV orbiter with the station due to its sideways attitude. Second, when an additional orbiter is docked to the port node, the clearance between the two orbiters is minimal. These two concerns removed this option from consideration, and no further analysis was performed on this option.

opt2-a front

ASSEMBLY COMPLETE WITH STARBOARD DOCKING MAST MOVED TO SIDE OF FORWARD STARBOARD NODE (FRONT VIEW)

OPTION 2-A



ISSUES:
- RENDEZVOUS AND DOCKING
- CLEARANCE

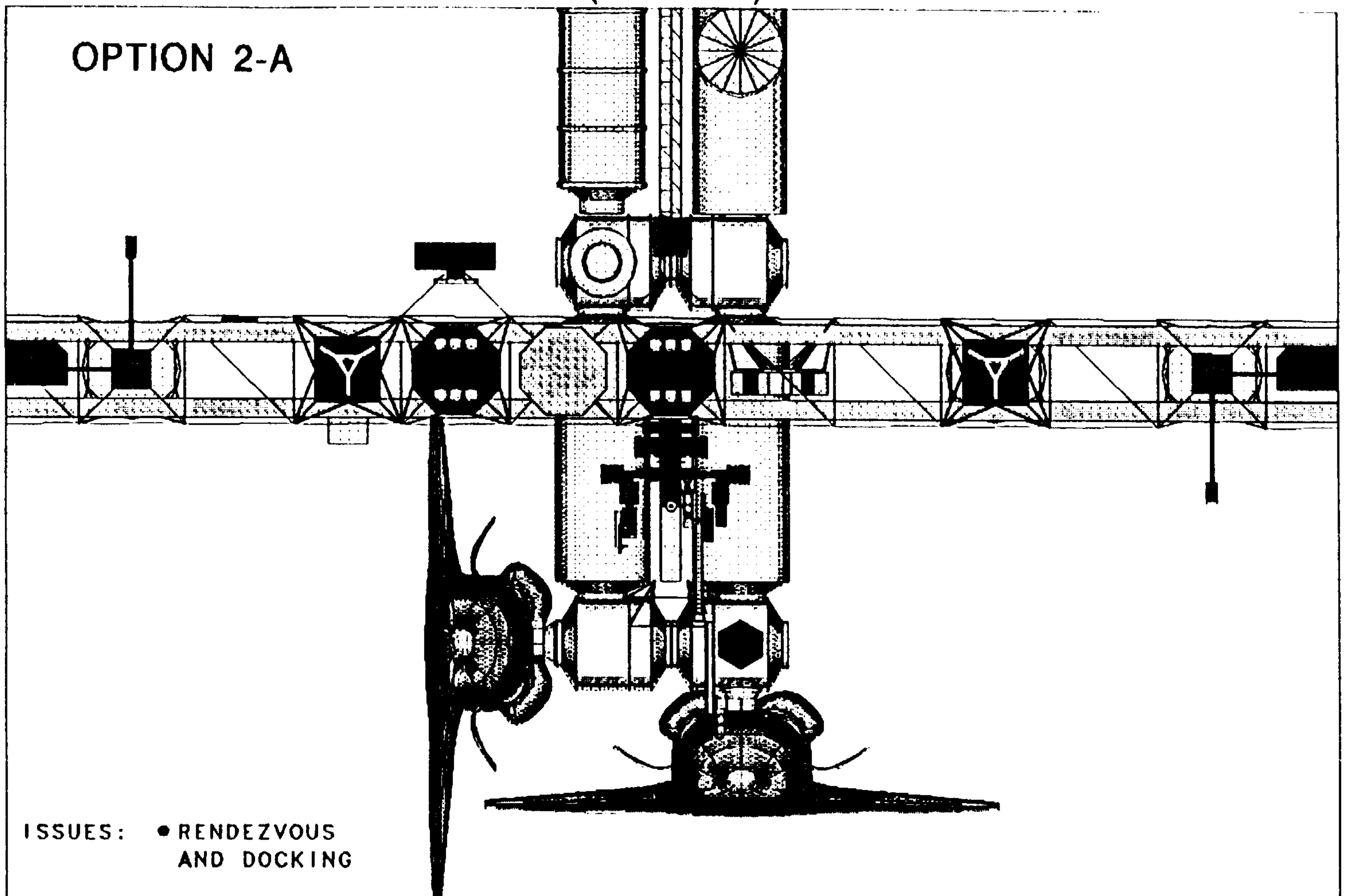
Assembly Complete with Starboard Docking Mast Moved to Side of Forward Starboard Node (Option 2–A) - Top View

This top view of Option 2–A shows the lack of adequate clearance between the wing of the orbiter docked on the front of the port node and the wing and payload bay door of the orbiter docked on the side of the starboard node.

opt2-a top

ASSEMBLY COMPLETE WITH STARBOARD DOCKING MAST MOVED TO SIDE OF FORWARD STARBOARD NODE (TOP VIEW)

OPTION 2-A



ISSUES:
- RENDEZVOUS AND DOCKING
- CLEARANCE

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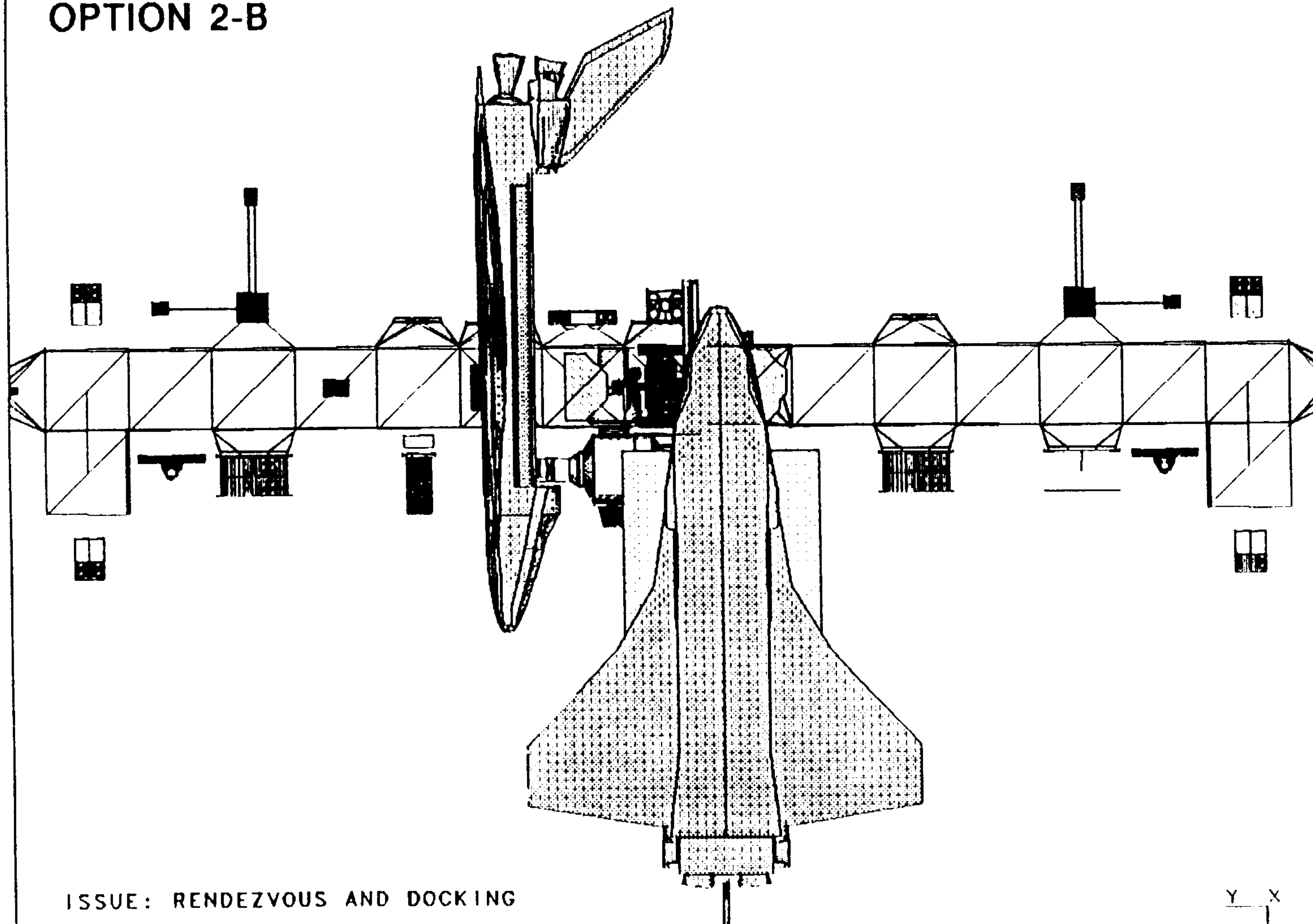
Assembly Complete with Starboard Docking Mast Moved to Side of Forward Starboard Node and Orbiter Tail Up (Option 2-B) - Front View

This configuration is similar to option 2-A except that the ACRV orbiter berthed to the side of the starboard node is in a tail-up attitude. This solves the clearance problems between the two orbiters, but the issue of rendezvous and docking still remains. Therefore, no further analysis was performed on this option.

opt2-b front

ASSEMBLY COMPLETE WITH STARBOARD DOCKING MAST MOVED TO SIDE OF FORWARD STARBOARD NODE (TAIL UP)

OPTION 2-B



ISSUE: RENDEZVOUS AND DOCKING

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Modified Hardware Approach

Option 3 replaced the baseline resource nodes with *extended* resource nodes, each of which are 42 inches longer than the standard resource node. This was done to determine if sufficient clearance was available with both orbiters simultaneously docked. The first orbiter was at the nominal location on the port resource node in a tail–down attitude, while the ACRV orbiter was located on the starboard node in a tail–up attitude.

option 3

Orbiter Utilization as an ACRV

Modified Hardware Approach

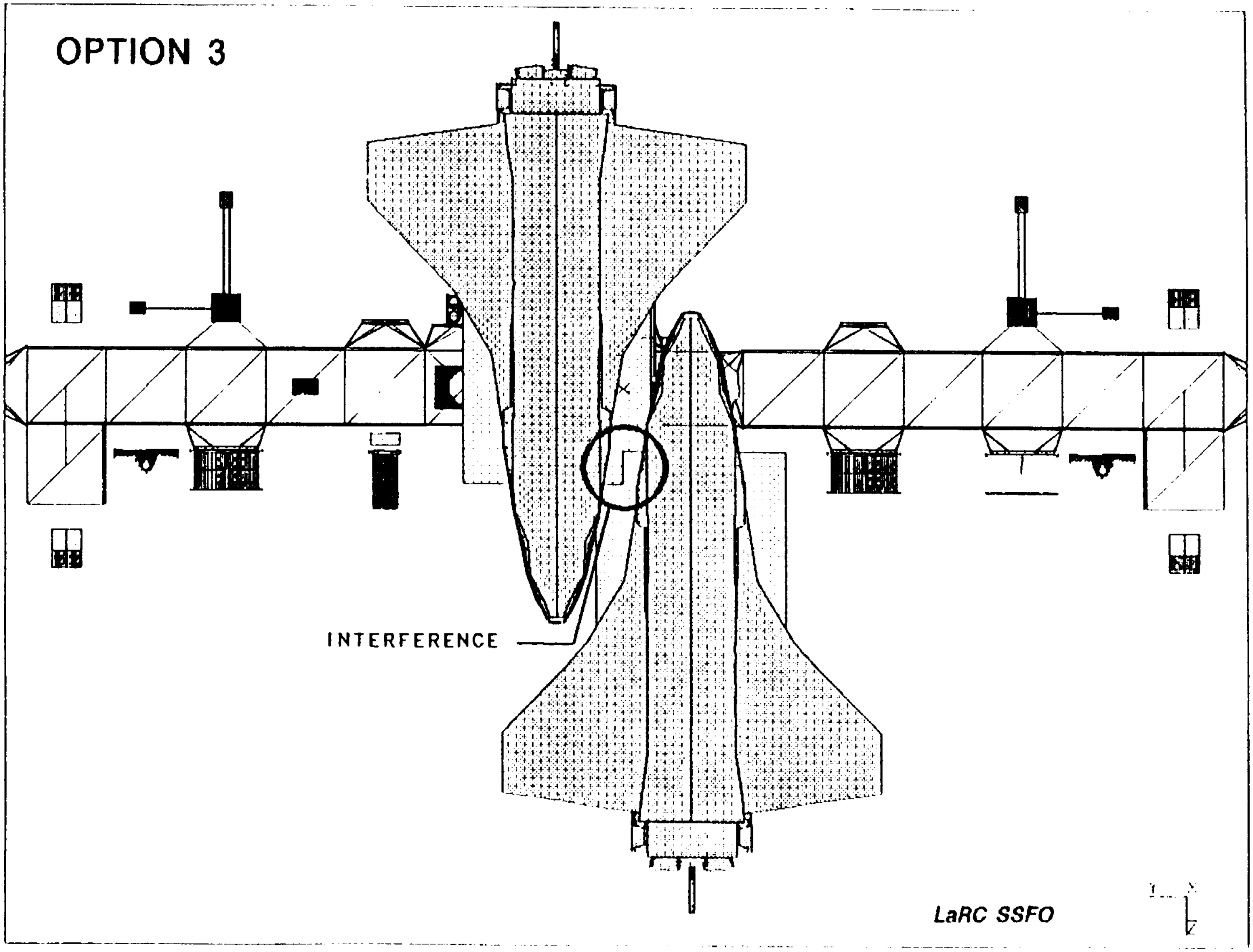
- Nominal Orbiter on front port resource node – facing forward, tail down. Six modified hardware locations considered for ACRV Orbiter :
  - **Option 2 :** Move starboard node docking mechanism to end port
    - **A.** ACRV Orbiter tail down
    - **B.** ACRV Orbiter tail up
  - **Option 3 :** Replace baseline resource nodes with *extended* resource nodes ; ACRV Orbiter on starboard node, forward, tail up
  - **Option 4 :** ACRV Orbiter attached to *additional* starboard node, forward, tail up
  - **Option 5 :** ACRV Orbiter attached to *additional extended* starboard node, forward, tail up
  - **Option 6 :** ACRV Orbiter attached to modified logistics module, nose forward
  - **Option 7 :** ACRV Orbiter attached to modified ESA module, nose forward

Assembly Complete with All Four Nodes Replaced by Extended Resource Nodes (Option 3)

In this option, each of the four nodes have been replaced by an extended resource node (ERN). An extended resource node, although not part of the baseline station, is planned for use in evolutionary growth of the station. An external resource node differs in outer dimensions from a standard resource node only in its length, which is 42 inches greater than that of a standard node. However, the use of the ERN did not sufficiently increase the clearance from option 1-A, and so interference still occurs between the two orbiters. Therefore, no further analysis was performed on this option.

opt3 front

ASSEMBLY COMPLETE WITH ALL FOUR NODES REPLACED BY EXTENDED RESOURCE NODES



Modified Hardware Approach

Option 4 attached an *additional* starboard node outboard of the nominal node. The motivation was to determine if sufficient clearance existed to accommodate two orbiters simultaneously. Here the ACRV orbiter was attached to the additional node in a tail–up attitude.

option 4

NASA — FREEDOM

Orbiter Utilization as an ACRV

Modified Hardware Approach

- Nominal Orbiter on front port resource node – facing forward, tail down. Six modified hardware locations considered for ACRV Orbiter :
  - **Option 2 :** Move starboard node docking mechanism to end port
    - **A.** ACRV Orbiter tail down
    - **B.** ACRV Orbiter tail up
  - **Option 3 :** Replace baseline resource nodes with *extended* resource nodes ; ACRV Orbiter on starboard node, forward, tail up
  - **Option 4 :** ACRV Orbiter attached to *additional* starboard node, forward, tail up
  - **Option 5 :** ACRV Orbiter attached to *additional extended* starboard node, forward, tail up
  - **Option 6 :** ACRV Orbiter attached to modified logistics module, nose forward
  - **Option 7 :** ACRV Orbiter attached to modified ESA module, nose forward

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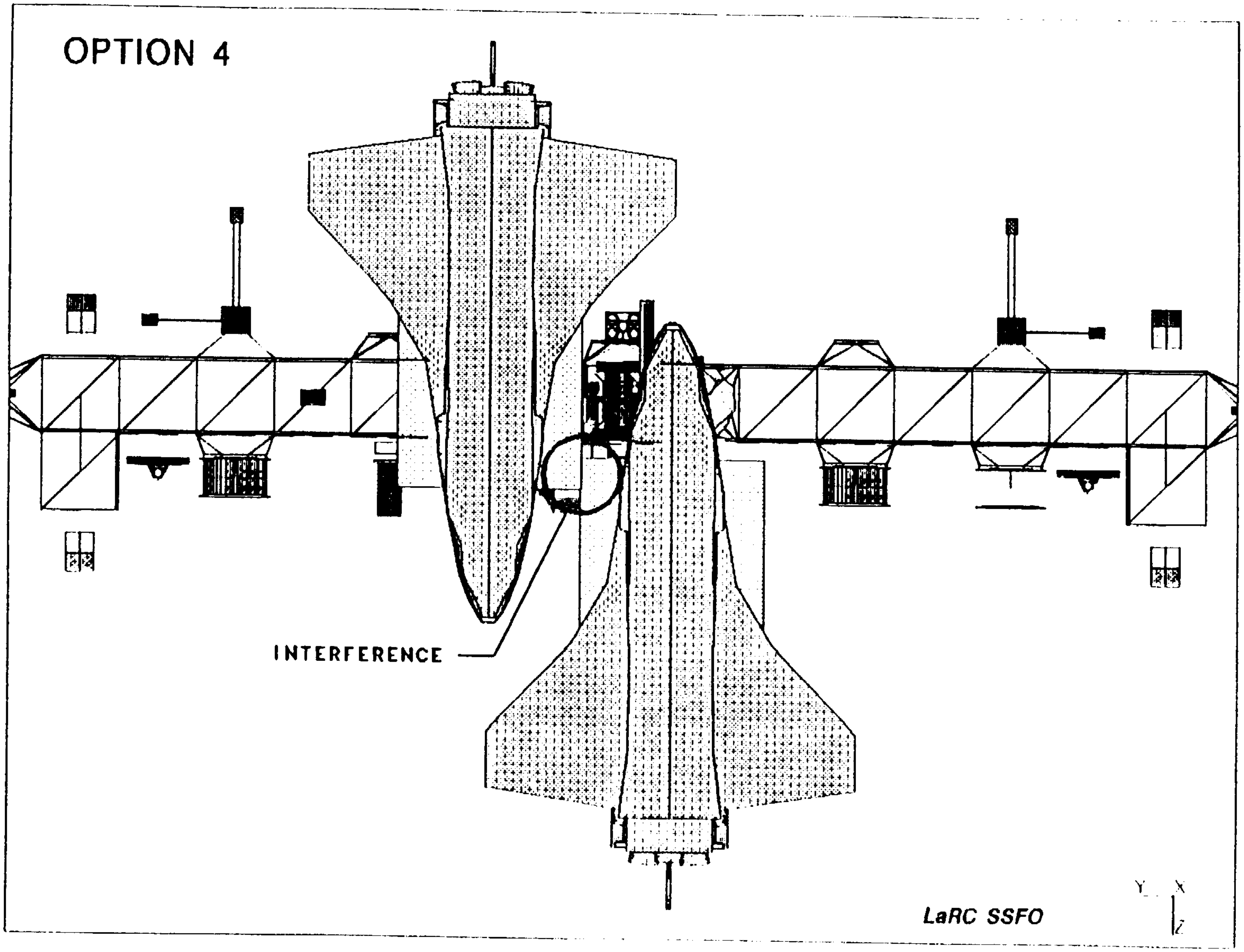
Orbiter/ACRV

Assembly Complete with One Additional Node Attached to Forward Starboard Node (Option 4)

In this option, an additional node has been added to the side of the starboard node to allow more distance between the two docked orbiters. However, a small amount of interference occurs with this option, so it too was not considered as a viable option. Therefore, no further analysis was performed on this option.

opt4 front

ASSEMBLY COMPLETE WITH ONE ADDITIONAL NODE ATTACHED TO FORWARD STARBOARD NODE



Modified Hardware Approach

Option 5 attached an *additional extended* resource node to the existing nominal starboard node. The ACRV orbiter was located on this new node in a tail-up attitude.

option 5

Orbiter Utilization as an ACRV

Modified Hardware Approach

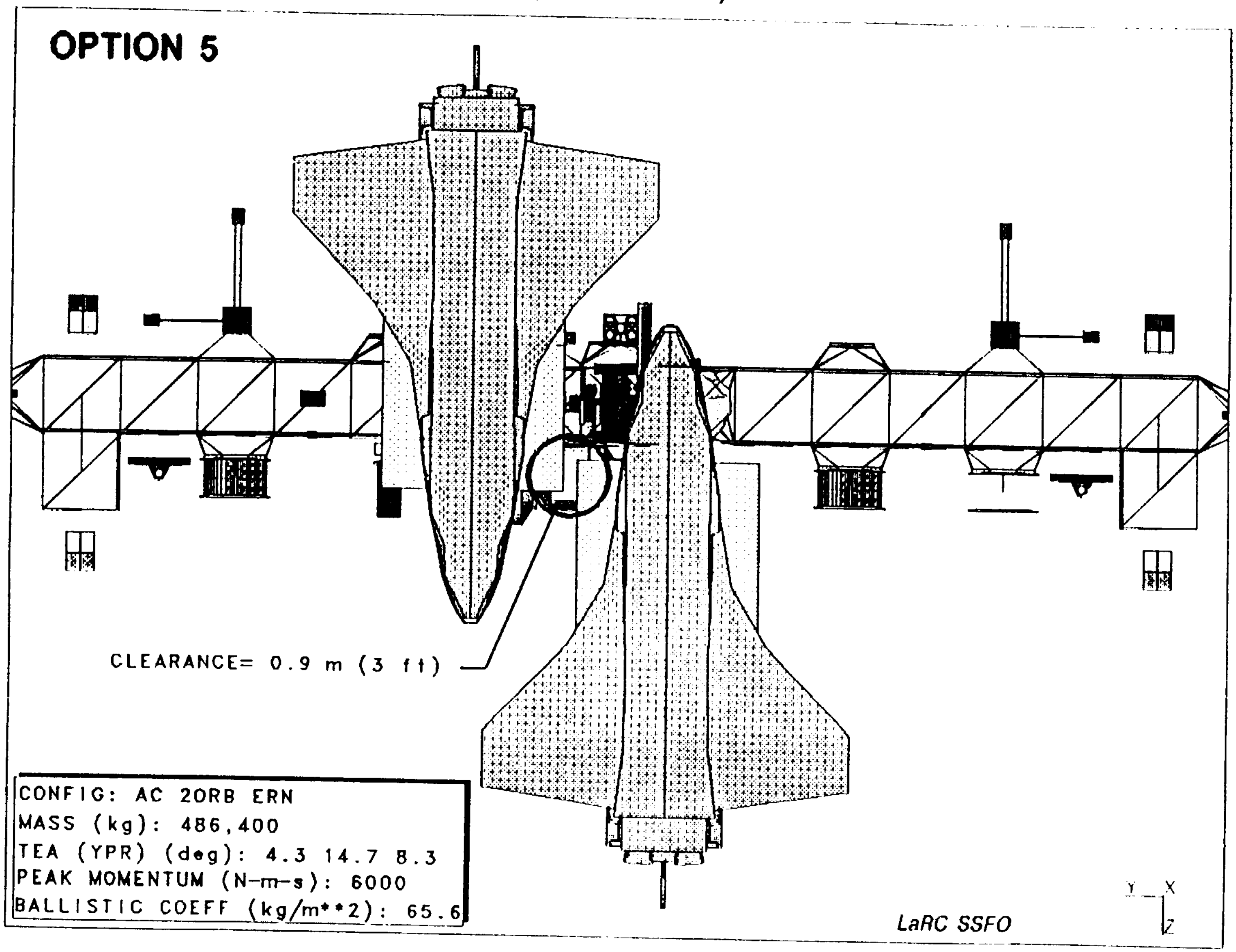
- Nominal Orbiter on front port resource node – facing forward, tail down. Six modified hardware locations considered for ACRV Orbiter :
  - **Option 2 :** Move starboard node docking mechanism to end port
    - **A.** ACRV Orbiter tail down
    - **B.** ACRV Orbiter tail up
  - **Option 3 :** Replace baseline resource nodes with *extended* resource nodes ; ACRV Orbiter on starboard node, forward, tail up
  - **Option 4 :** ACRV Orbiter attached to *additional* starboard node, forward, tail up
  - **Option 5 :** ACRV Orbiter attached to *additional extended* starboard node, forward, tail up
  - **Option 6 :** ACRV Orbiter attached to modified logistics module, nose forward
  - **Option 7 :** ACRV Orbiter attached to modified ESA module, nose forward

Assembly Complete with One Extended Resource Node Attached to Forward Starboard Node (Option 5) - Front View

In this configuration an extended resource node (ERN) has been added to the side of the forward starboard node to provide even greater distance between the two docked orbiters than option 4. The additional 42 inches provided by an ERN, compared to a standard resource node, allowed for a three foot clearance between the two orbiters. The small amount of clearance involved here did raise some concerns as to the potential for collision between the orbiters' payload bay doors, but a complete analysis was still performed on this option. The primary results of this analysis are summarized in the box in the bottom left of the figure.

opt5 front

ASSEMBLY COMPLETE WITH ONE EXTENDED RESOURCE NODE
ATTACHED TO FORWARD STARBOARD NODE
(FRONT VIEW)

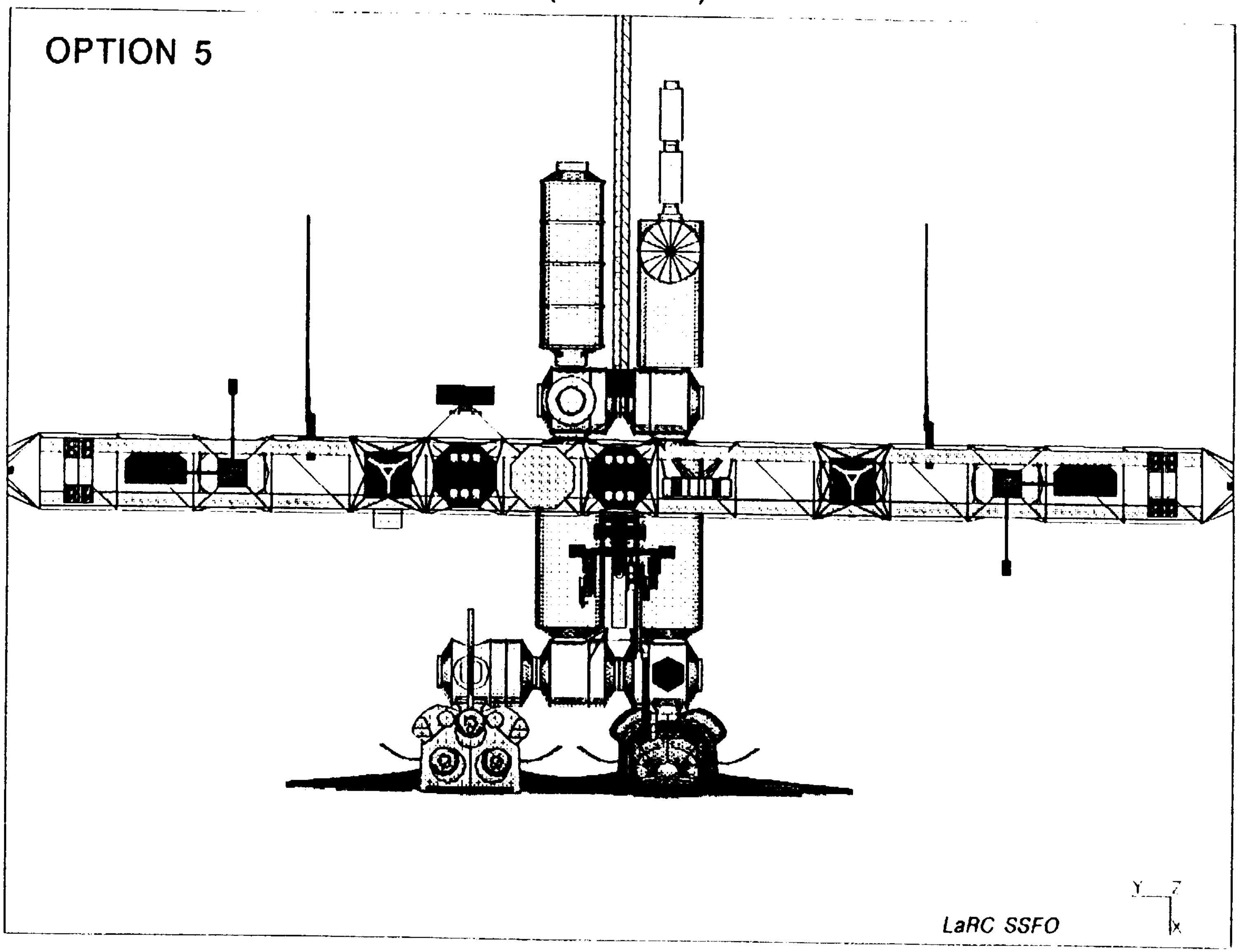


Assembly Complete with One Extended Resource Node Attached to Forward Starboard Node (Option 5) - Top View

This top view of option 5 shows the minimal amount of clearance between the payload bay doors of the two orbiters. The placement of the extended resource node is also clearly seen.

opt5 top

ASSEMBLY COMPLETE WITH ONE EXTENDED RESOURCE NODE
ATTACHED TO FORWARD STARBOARD NODE
(TOP VIEW)



PMC with One Extended Resource Node Attached to Forward Starboard Node
Steady State Microgravity Contours
(Option 5)

This is the option 5 configured PMC station with an ACRV orbiter docked to the extended resource node added on the starboard side. The contours show the envelopes of the one and two microgravity environments. The view is from the starboard side and the station is oriented to its pitch TEA of -37.5 degrees. Note that only approximately 50% of the pressurized lab volume falls within the one μG contour.

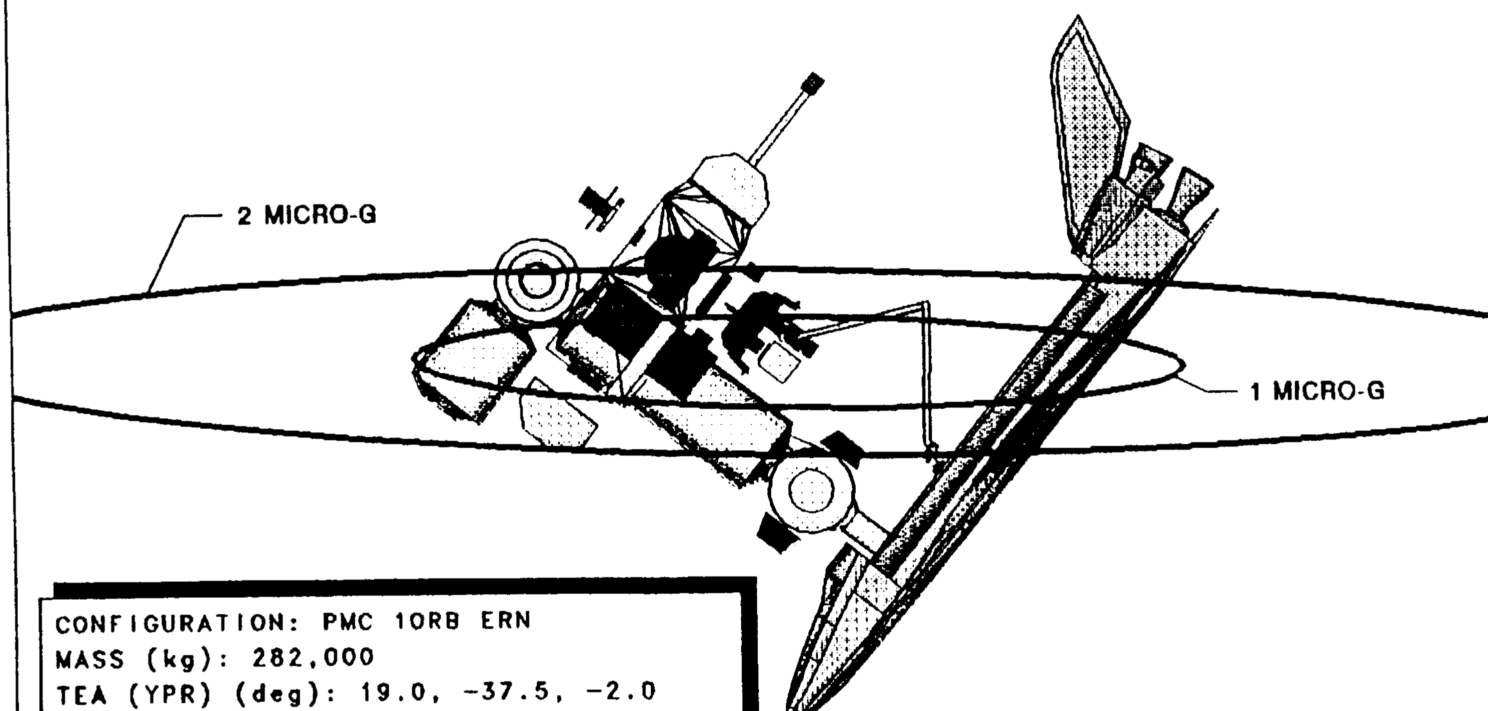
opt5 pmc-mg

PMC WITH ONE EXTENDED RESOURCE NODE ATTACHED TO FORWARD STARBOARD NODE

STEADY STATE MICROGRAVITY CONTOURS

SIDE VIEW

OPTION 5



CONFIGURATION: PMC 1ORB ERN
MASS (kg): 282,000
TEA (YPR) (deg): 19.0, -37.5, -2.0
APPROX 1 MICRO-G US LAB VOLUME: 50%
APPROX 1 MICRO-G TOTAL LAB VOLUME: 50%
PEAK CONTROL MOMENTUM (N-m-s): 7400
BALLISTIC COEFFICIENT (kg/m**2): 60.6
REBOOST FUEL (45 DAYS) (lbs): 2650

VELOCITY
NADIR

LaRC SSFO

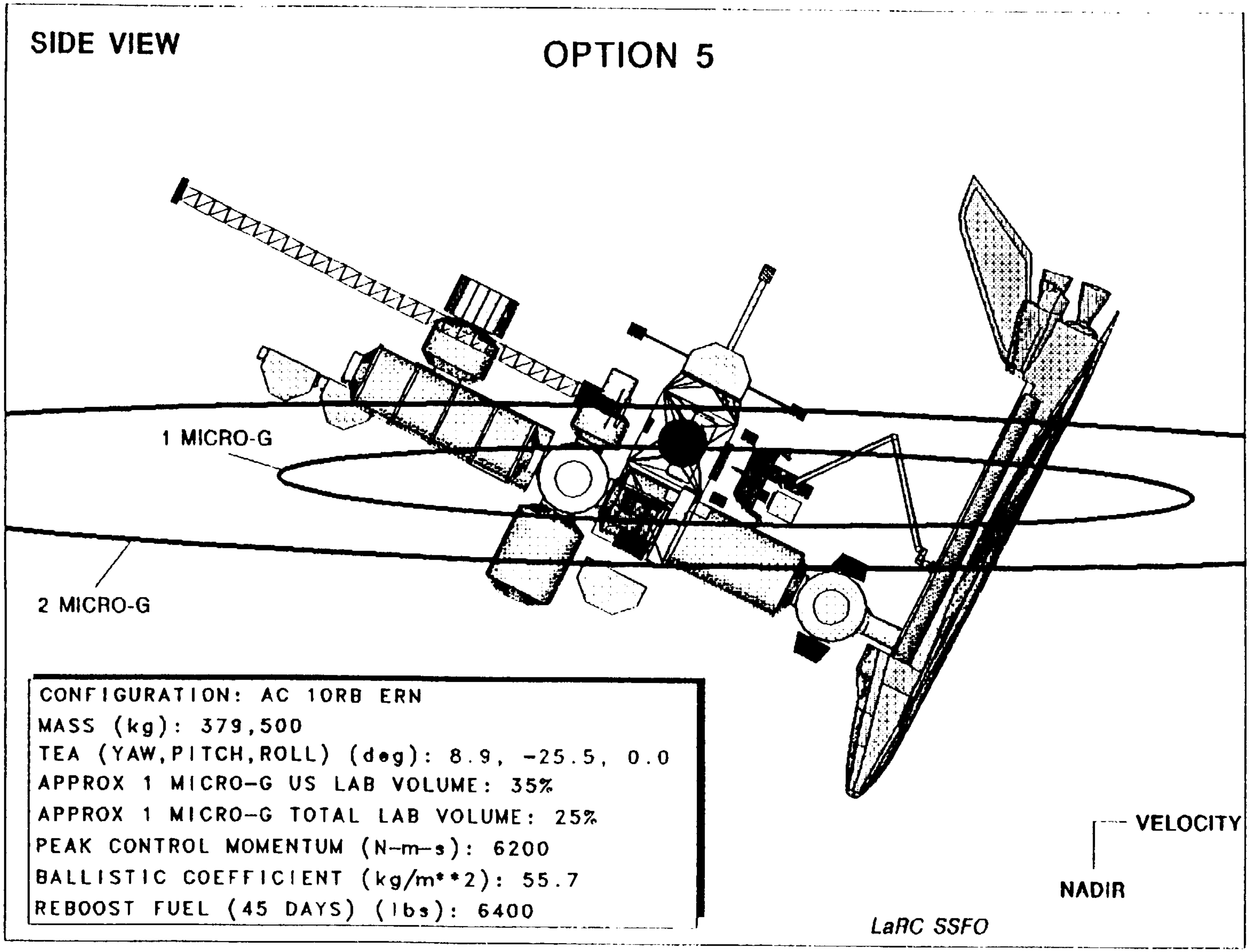
Assembly Complete with One Extended Resource Node Attached to Forward Starboard Node
Steady State Microgravity Contours
(Option 5)

This is the option 5 configured Assembly Complete station with an ACRV orbiter docked to the extended resource node added on the starboard side. The contours show the envelopes of the one and two microgravity environments. The view is from the starboard side and the station is oriented to its pitch TEA of -25.5 degrees. Note that only approximately 35% of the total lab volume is within the one μG contour and only 25% of the US lab volume is located in the one μG environment.

opt5 ac-mg

ASSEMBLY COMPLETE WITH ONE EXTENDED RESOURCE NODE ATTACHED TO FORWARD STARBOARD NODE

STEADY STATE MICROGRAVITY CONTOURS



Modified Hardware Approach

In option 6, the logistics module located aft and beneath the pressurized US lab module was modified to accommodate a docking mechanism. The ACRV orbiter was located on this module, oriented in a nose forward attitude.

option 6

Orbiter Utilization as an ACRV

Modified Hardware Approach

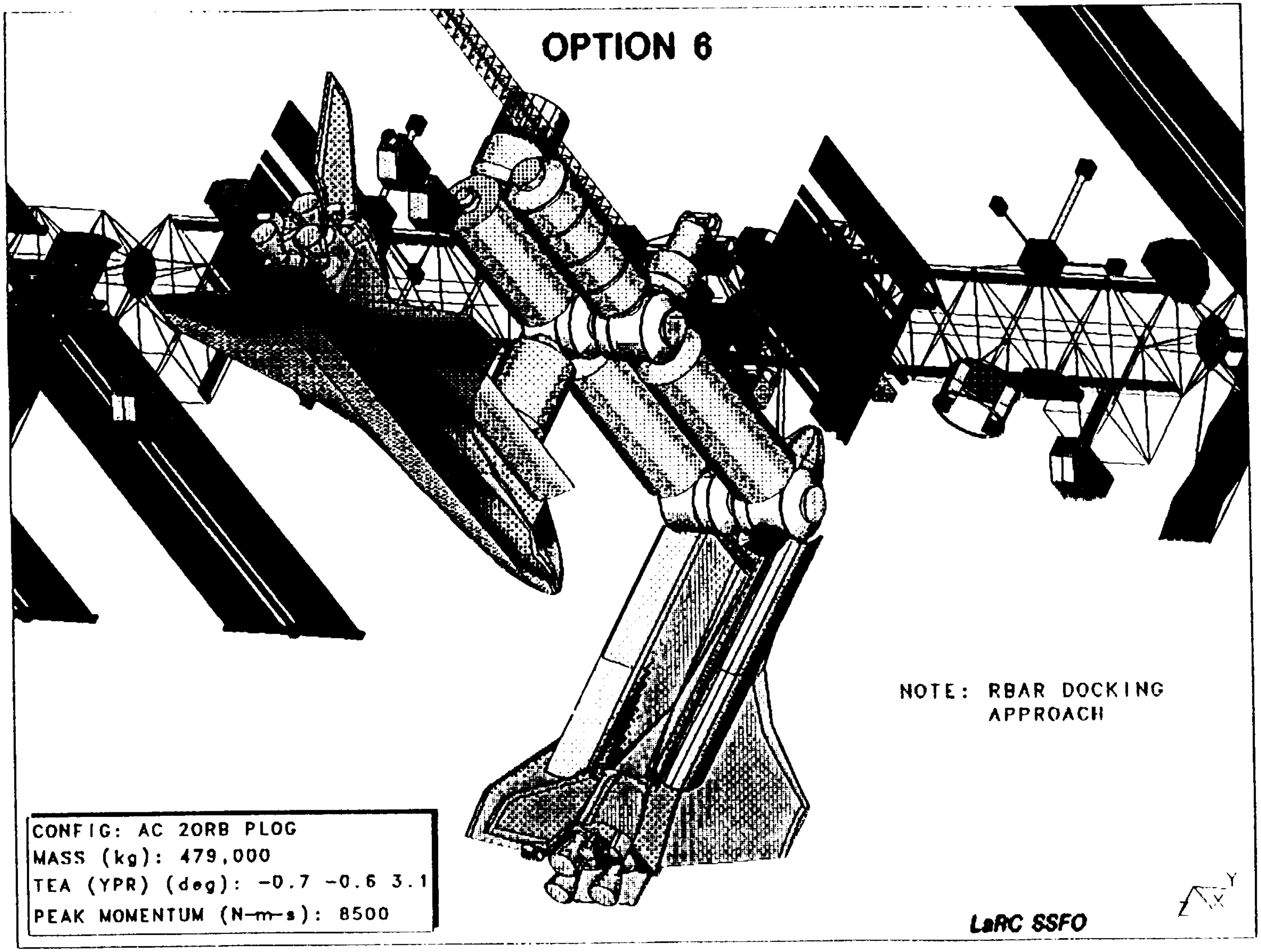
- Nominal Orbiter on front port resource node – facing forward, tail down. Six modified hardware locations considered for ACRV Orbiter :
  - **Option 2 :** Move starboard node docking mechanism to end port
    - **A.** ACRV Orbiter tail down
    - **B.** ACRV Orbiter tail up
  - **Option 3 :** Replace baseline resource nodes with *extended* resource nodes ; ACRV Orbiter on starboard node, forward, tail up
  - **Option 4 :** ACRV Orbiter attached to *additional* starboard node, forward, tail up
  - **Option 5 :** ACRV Orbiter attached to *additional extended* starboard node, forward, tail up
  - **Option 6 :** ACRV Orbiter attached to modified logistics module, nose forward
  - **Option 7 :** ACRV Orbiter attached to modified ESA module, nose forward

Assembly Complete with Docking Mast Added to Pressurized Logistics Module (Option 6)

In this option a docking mast was added to the pressurized logistics module, which in this view is located on the underside of the aft port node. This option avoids any clearance problems between the two orbiters, but raises the issues of nadir viewing from the JEM exposed facility and the fact that an Rbar approach is required to dock to the pressurized logistics module. Analysis for this option was performed on both the PMC and AC configurations.

opt6 iso

ASSEMBLY COMPLETE WITH DOCKING MAST ADDED TO PRESSURIZED LOGISTICS MODULE



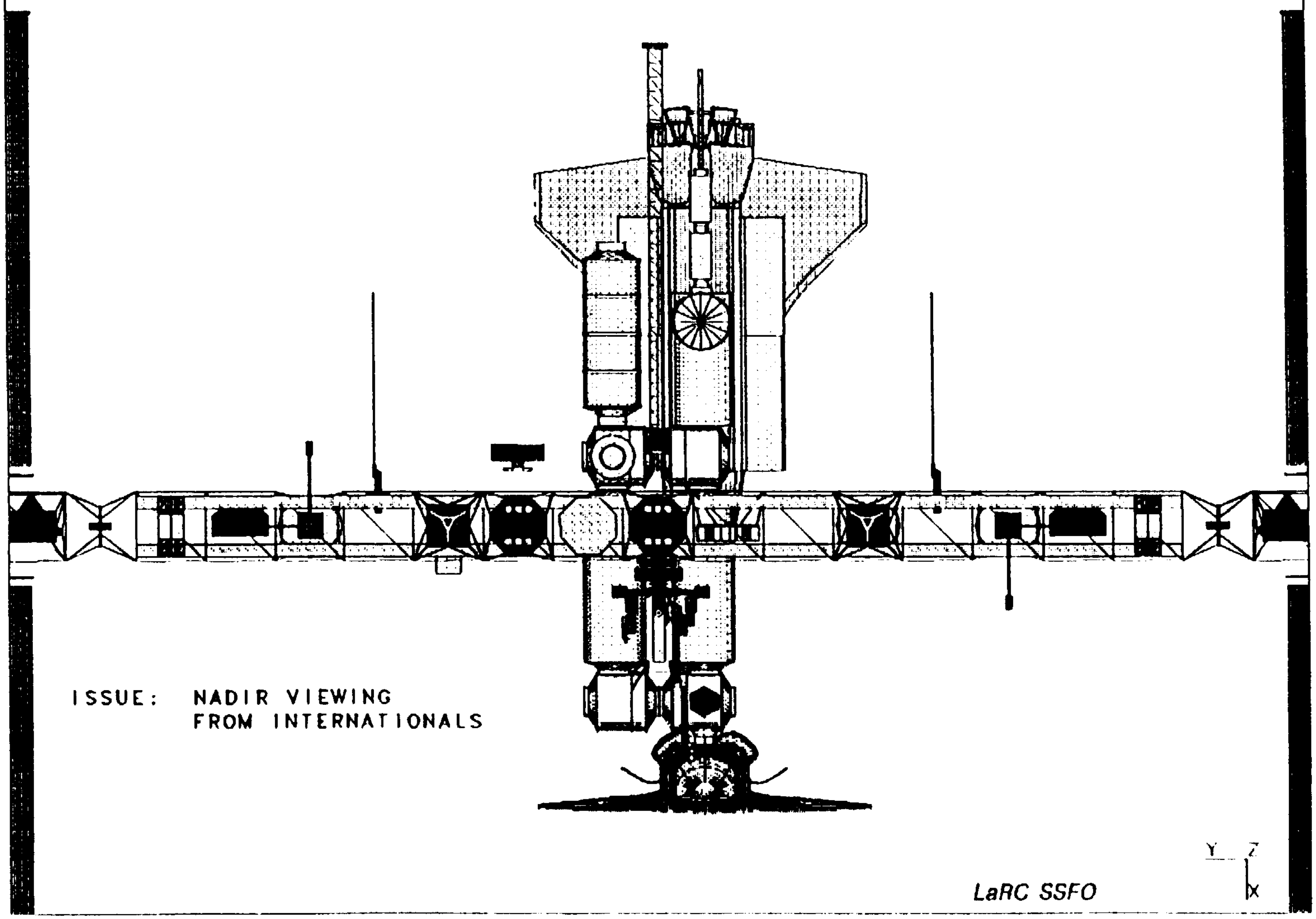
Assembly Complete with Docking Mast Added to Pressurized Logistics Module (Option 6) - Top View

This top view of option 6 shows the potential problems for nadir viewing from the international modules and potential station heat radiation blockage.

opt6 top

ASSEMBLY COMPLETE WITH DOCKING MAST ADDED TO PRESSURIZED LOGISTICS MODULE (TOP VIEW)

OPTION 6



PMC with Docking Mast Added to Pressurized Logistics Module
Steady State Microgravity Contours
(Option 6)

This is a side view of option 6 configured PMC station with an ACRV orbiter docked to the pressurized logistics module. The contours show the envelopes of the one and two microgravity environments with the configuration oriented to its pitch TEA of -30.8 degrees. As with all the PMC options, approximately 50% of the pressurized lab volume falls within the one μG contour.

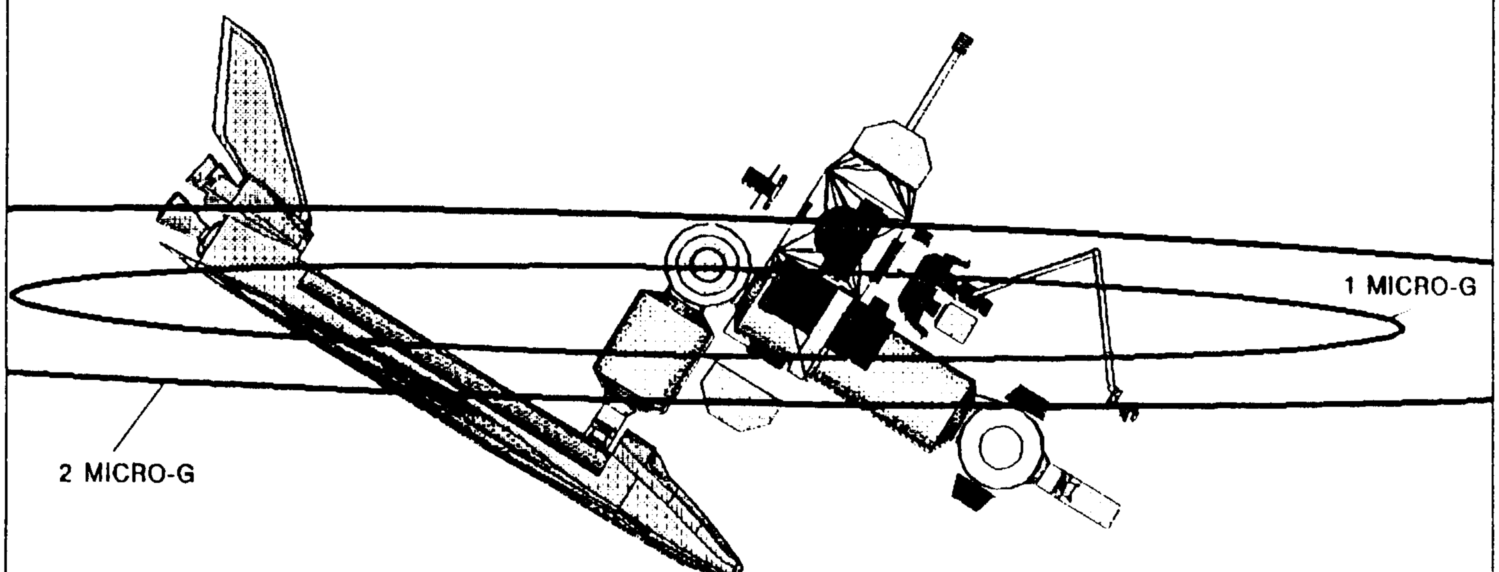
opt6 pmc-mg

PMC WITH DOCKING MAST ADDED TO PRESSURIZED LOGISTICS MODULE

STEADY STATE MICROGRAVITY CONTOURS

SIDE VIEW

OPTION 6



CONFIGURATION: PMC 1ORB PLOG
MASS (kg):274,600
TEA (YPR) (deg): 13.5, -30.8, 1.7
APPROX 1 MICRO-G US LAB VOLUME: 50%
APPROX 1 MICRO-G TOTAL LAB VOLUME: 50%
PEAK CONTROL MOMENTUM (N-m-s): 4500
BALLISTIC COEFFICIENT (kg/m**2): 63.7
REBOOST FUEL (45 DAYS) (lbs): 2550

VELOCITY

NADIR

LaRC SSFO

Assembly Complete with Docking Mast Added to Pressurized Logistics Module
Steady State Microgravity Contours
(Option 6)

This is a side view of option 6 configured AC station with an ACRV orbiter docked to the pressurized logistics module. In this view Freedom is oriented to its pitch TEA of –30.4 degrees. The contours show the envelopes of the one and two microgravity environments. Note that the international labs are almost entirely outside on the one μG volume and only approximately 40% of the US lab volume is within the one μG contour.

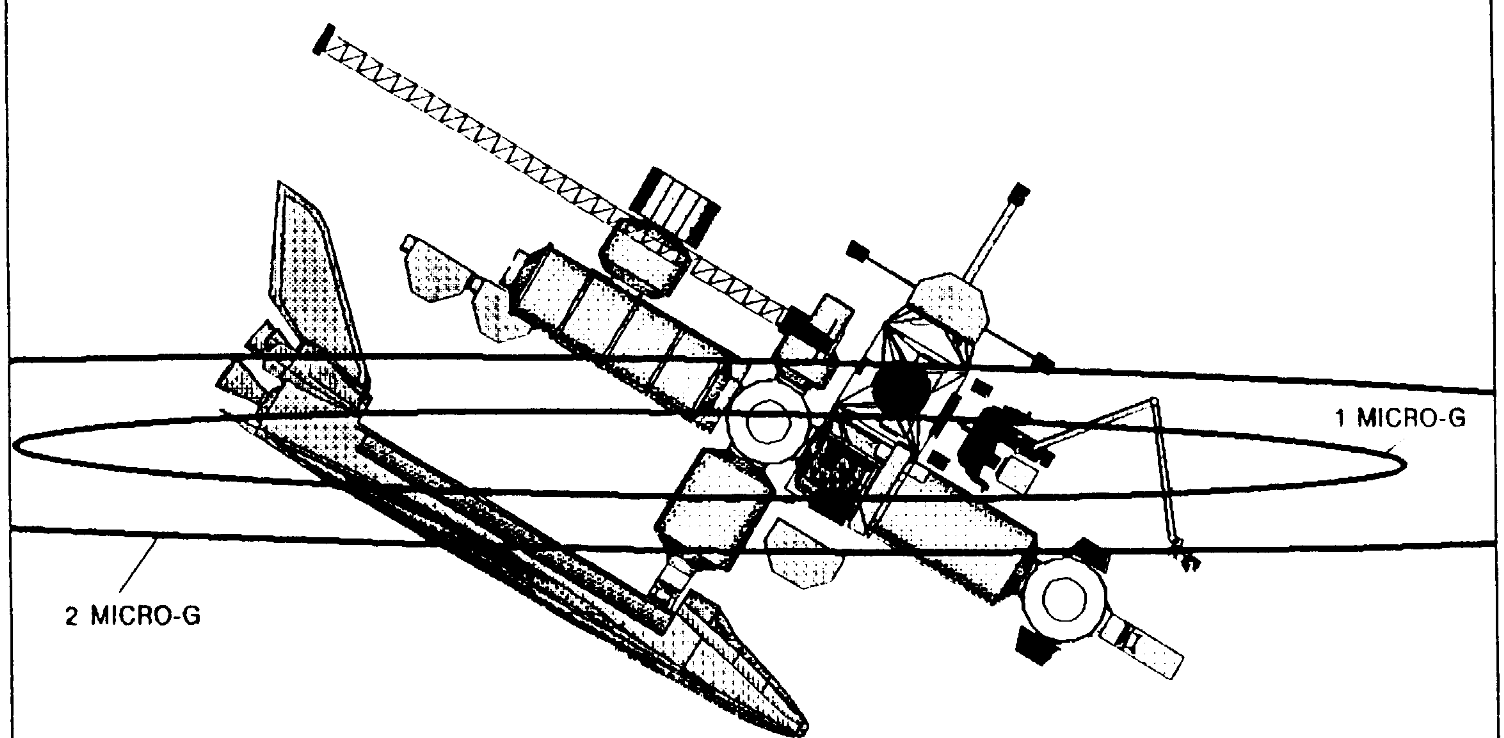
opt6 ac–mg

ASSEMBLY COMPLETE WITH DOCKING MAST ADDED TO PRESSURIZED LOGISTICS MODULE

STEADY STATE MICROGRAVITY CONTOURS

SIDE VIEW

OPTION 6



CONFIG: AC 1ORB PLOG   MASS (kg): 372,000
TEA (YPR) (deg): 2.8 -30.4 0.8
APPROX 1 MICRO-G US LAB VOLUME: 40%
APPROX 1 MICRO-G TOTAL LAB VOLUME: 15%
PEAK CONTROL MOMENTUM (N-m-s): 7600
BALLISTIC COEFFICIENT (kg/m**2): 58.6
REBOOST FUEL (45 DAYS) (lbs): 6200

VELOCITY

NADIR

LaRC SSFO

Modified Hardware Approach

In option 7, the ESA module (AC configuration only) had a node attached with a docking mechanism to accommodate the ACRV orbiter, which was oriented in a nose-forward attitude, located beneath the ESA module.

option 7

Orbiter Utilization as an ACRV

Modified Hardware Approach

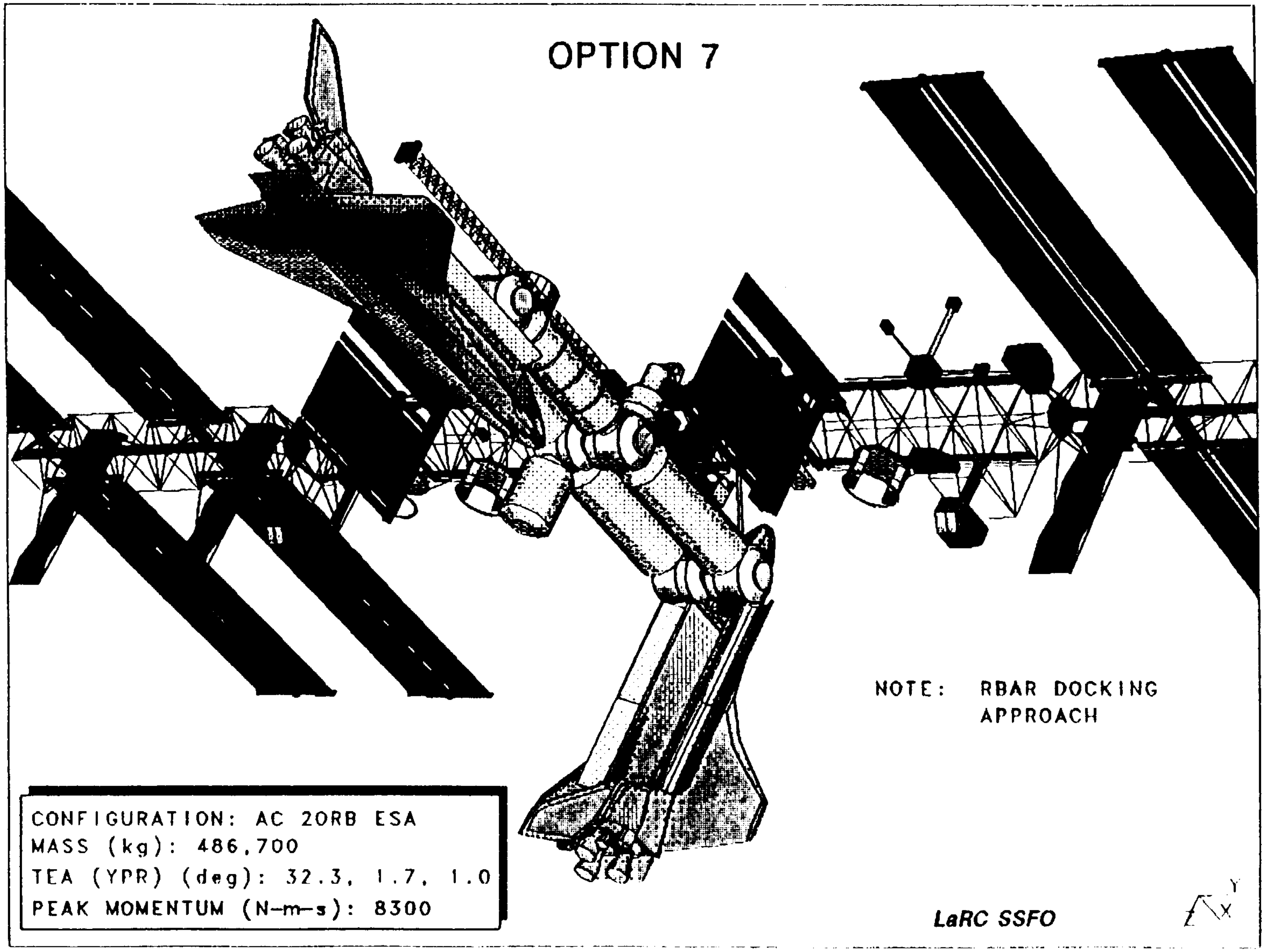
- Nominal Orbiter on front port resource node – facing forward, tail down. Six modified hardware locations considered for ACRV Orbiter :
  - **Option 2 :** Move starboard node docking mechanism to end port
    - **A.** ACRV Orbiter tail down
    - **B.** ACRV Orbiter tail up
  - **Option 3 :** Replace baseline resource nodes with *extended* resource nodes ; ACRV Orbiter on starboard node, forward, tail up
  - **Option 4 :** ACRV Orbiter attached to *additional* starboard node, forward, tail up
  - **Option 5 :** ACRV Orbiter attached to *additional extended* starboard node, forward, tail up
  - **Option 6 :** ACRV Orbiter attached to modified logistics module, nose forward
  - **Option 7 :** ACRV Orbiter attached to modified ESA module, nose forward

Assembly Complete with Additional Node and Docking Mast Attached to Aft End of ESA Module (Option 7)

This option minimizes the chance of collision between the two orbiters by having them docked as far apart as possible. There is still the problem of a required Rbar approach and restricted nadir viewing from the international modules. In addition, there is also the mass penalty associated with the additional required node. Analysis for this option was only performed on the AC configuration.

opt7 iso

ASSEMBLY COMPLETE WITH ADDITIONAL NODE AND DOCKING MAST ATTACHED TO AFT END OF ESA MODULE

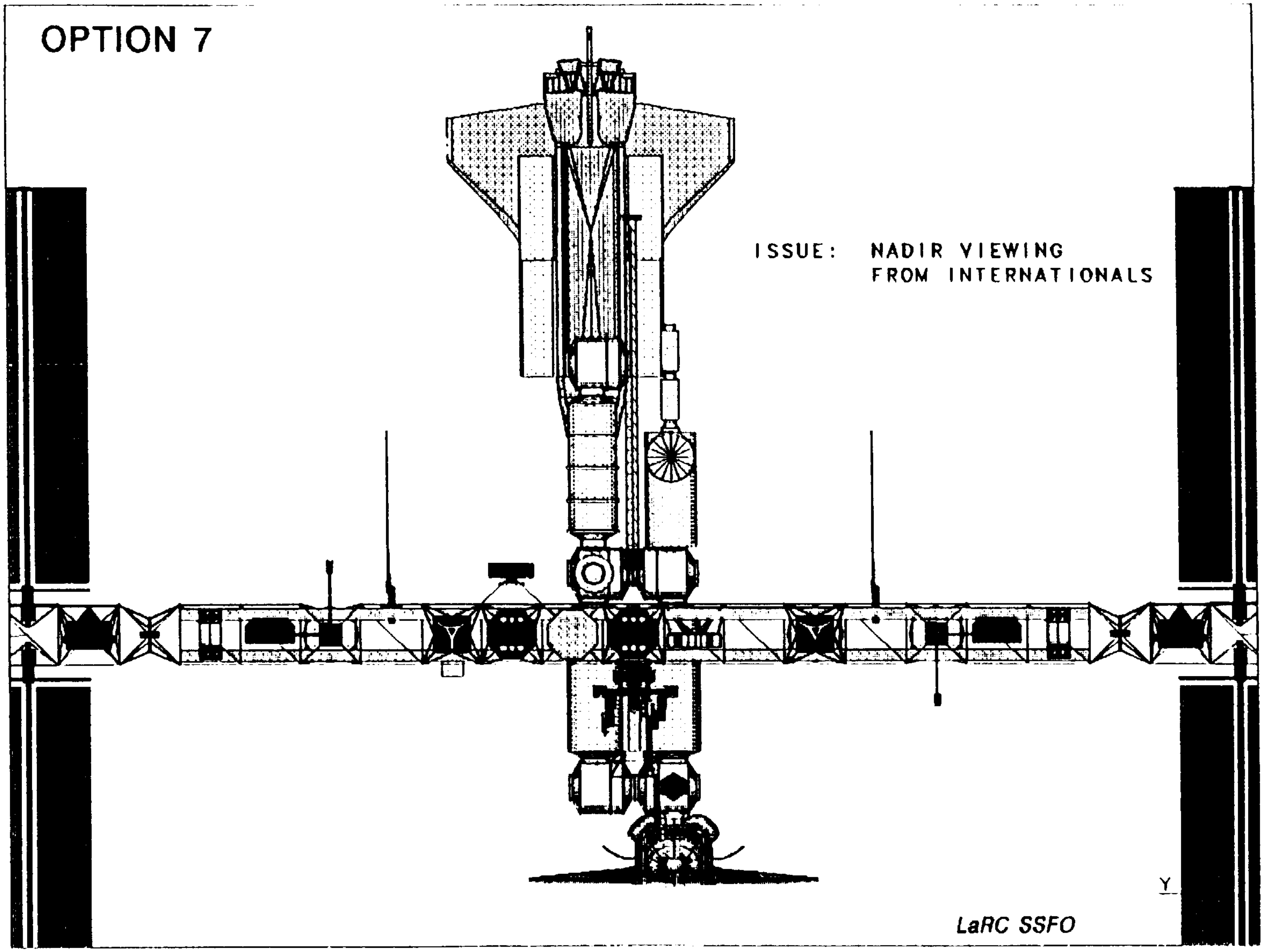


Assembly Complete with Additional Node and Docking Mast Attached to Aft End of ESA Module (Option 7) - Top View

This view shows the potential nadir viewing problems from the international modules caused by the ACRV orbiter being docked beneath them.

opt7 top

ASSEMBLY COMPLETE WITH ADDITIONAL NODE AND DOCKING MAST ATTACHED TO ESA MODULE (TOP VIEW)



Assembly Complete with Additional Node and Docking Mast Attached to ESA Module
Steady State Microgravity Contours
(Option 7)

This is a side view of the option 7 configured AC station with an ACRV orbiter docked to a node attached to the aft of the ESA module. The PMC station was not analyzed for this option due to the fact that the ESA module is not present at PMC. The station is oriented to its pitch TEA of −12.0 degrees. The contours show the limits of the one and two microgravity environments. This option allows a large percentage of the international lab volume to fall within the one μG contour, but only 40% of the US lab volume is within the one μG envelope.

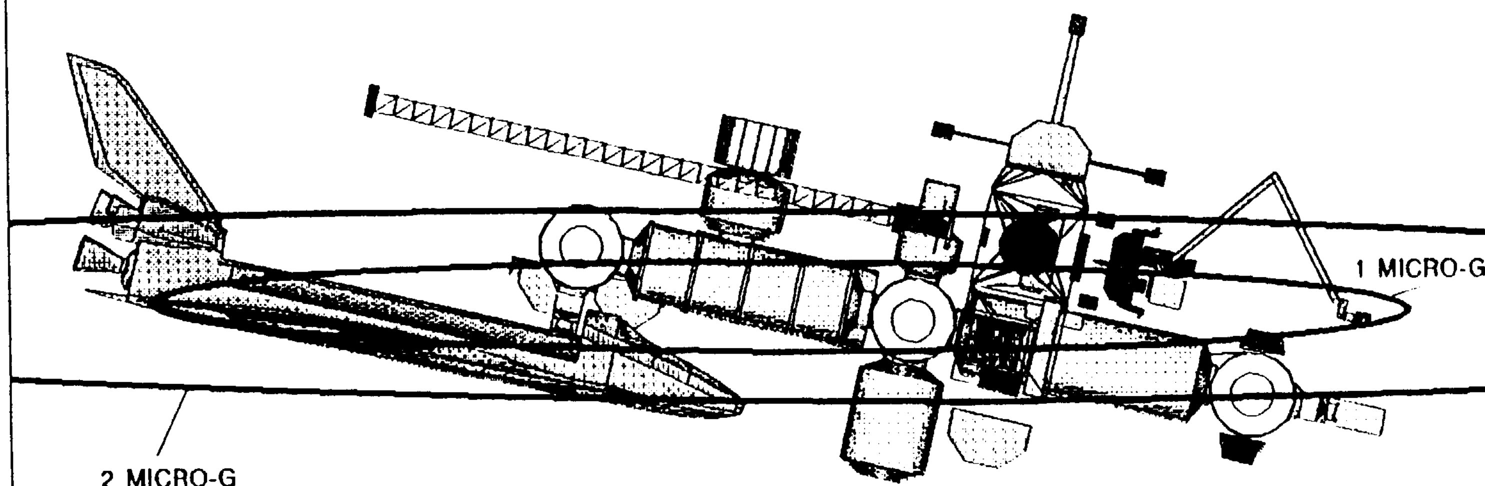
opt7 ac-mg

ASSEMBLY COMPLETE WITH ADDITIONAL NODE AND DOCKING MAST ATTACHED TO ESA MODULE

STEADY STATE MICROGRAVITY CONTOURS

SIDE VIEW

OPTION 7



CONFIGURATION: AC 1ORB ESA
MASS (kg): 379,800
TEA (YPR) (deg): -7.1, -12.0, 0.3
APPROX 1 MICRO-G US LAB VOLUME: 40%
APPROX 1 MICRO-G TOTAL LAB VOLUME: 65%
PEAK CONTROL MOMENTUM (N-m-s): 9400
BALLISTIC COEFFICIENT (kg/m**2): 63.3
REBOOST FUEL (45 DAYS) (lbs): 6200

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New Hardware Development

The last configuration considered, option 8, incorporates a new hardware design, namely an *oblique* docking mechanism. The oblique docking mechanism would be attached to a forward node, either in the front or perhaps at a lower port. This type of configuration allows the orbiter to essentially be utilized as ballast to drive the mass properties to obtain a desirable torque equilibrium attitude and microgravity environment. The "degree of obliqueness" is configuration dependent. For AC, the angular offset of the docking mechanism was approximately 27 degrees. A *fixed* oblique docking mechanism would thus be optimal for one configuration only, offering varying degrees of reduced attitude improvement for other configurations. On the other hand, a *hinged* docking mechanism could be rotated to the optimal angle to obtain the desirable attitude and microgravity for all station configurations. In either case, a Vbar approach would be preserved for the docking or berthing procedure.

option 8

Orbiter Utilization as an ACRV

NEW HARDWARE DEVELOPMENT APPROACH

- **Option 8 :** *Oblique* docking mechanism design attached to forward port node
  - Approximately 27 degrees for AC configuration
  - Will vary from configuration to configuration

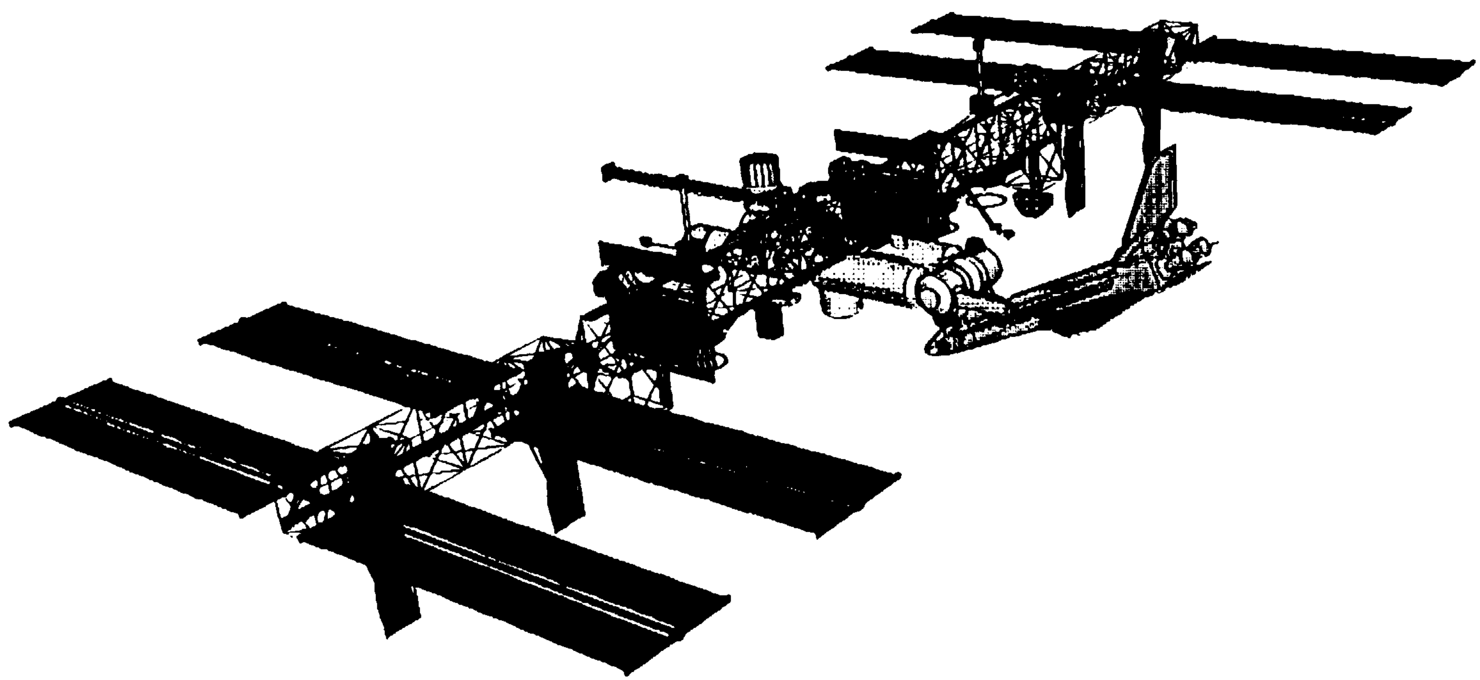
Assembly Complete with Orbiter Attached to Oblique Docking Adapter
(Orbiter Rotated 27 Degrees from Horizontal)
(Option 8)

This is the new hardware approach that was considered in this study. A new docking mast design would be used on the forward node for use by an orbiter. The docking adapter would be positioned at an optimal angle for each particular stage of station construction. In this particular case (Assembly Complete), the adapter angled at 27 degrees provides a nearly zero pitch TEA, and also maximizes the lab volume contained within the one microgravity environment. This approach could also be adapted for use by the resupply orbiter even if there is no ACRV orbiter present.

opt8 iso

ASSEMBLY COMPLETE WITH ORBITER ATTACHED TO OBLIQUE DOCKING ADAPTER
(ORBITER ROTATED 27 DEG. FROM HORIZONTAL)

OPTION 8



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Assembly Complete with Orbiter Attached to Oblique Docking Adapter (Orbiter Rotated 27 Deg. from Horizontal) Steady State Microgravity Contours (Option 8)

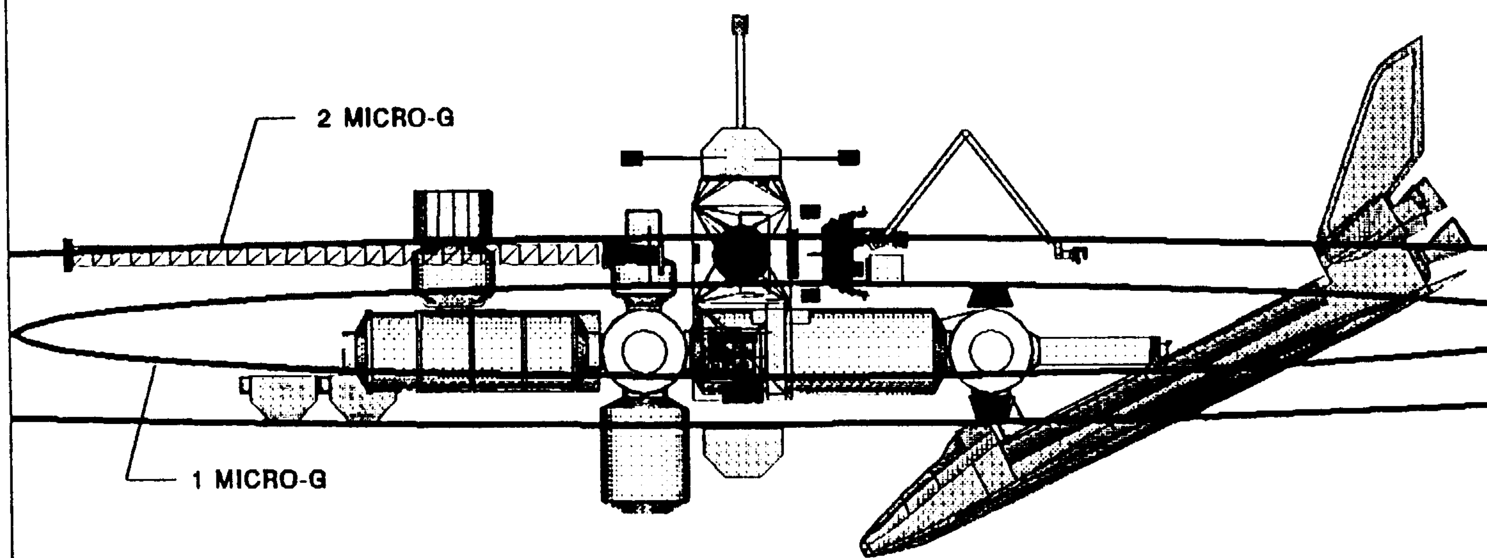
This view shows the microgravity profile of the Assembly Complete station with the oblique docking adapter being used. Notice that the use of this adapter can result in a nearly zero pitch TEA angle (–0.2 degrees in this case). Also, approximately 85% of the total the station lab volume is within the one microgravity envelope, which is considerably more than the amount achieved by the modified hardware approaches or even the baseline space station configurations. If an orbiter is to be berthed to Freedom for extended periods of time, this would be a preferred method of positioning it.

opt8 ac-mg

ASSEMBLY COMPLETE WITH ORBITER ATTACHED TO OBLIQUE DOCKING ADAPTER
(ORBITER ROTATED 27 DEG. FROM HORIZONTAL)
STEADY STATE MICROGRAVITY CONTOURS

SIDE VIEW

OPTION 8



CONFIGURATION: AC 1ORB OBL
MASS (kg): 372,000
TEA (YPR) (deg): -4.3, -0.2, 0.6
APPROX 1 MICRO-G US LAB VOLUME: 85%
APPROX 1 MICRO-G TOTAL LAB VOLUME: 85%
PEAK CONTROL MOMENTUM (N-m-s): 3900
BALLISTIC COEFFICIENT (kg/m**2): 66
REBOOST FUEL (45 DAYS) (lbs): 6125

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VELOCITY

NADIR

PMC Analysis Results

The facing page summarizes in tabular form the results obtained for the PMC options studied. Only options which could accommodate two orbiters simultaneously were analyzed. Flight characteristics summarized include Torque Equilibrium Attitude (TEA) given in a yaw, pitch, and roll sequence (expressed in degrees); the percent of the steady state one μG volume existing in the pressurized US lab module; the peak momentum requirements to maintain the TEA using CMGs (expressed in Newton–meter–seconds); and the fuel reboost requirements (expressed in pounds), consistent with the 45 day reboost assumptions stated earlier. Single attached orbiter configurations examined included the baseline configuration, as well as options 5 and 6. Likewise, the TEA and peak momentum requirements for options 5 and 6 were analyzed with two orbiters attached.

Although all single orbiter configurations studied had a total of approximately 50% of the lab volume within the one μG envelope, the sensed acceleration direction varied significantly as indicated by the various TEAs listed. All CMG peak momentum requirements were handled by two CMGs (six are planned for *Freedom*). Of significance was the approximately 70% increase in reboost fuel requirements with an ACRV orbiter attached.

Orbiter Utilization as an ACRV

PMC ANALYSIS RESULTS

Configuration	TEA (deg)	Percent 1 μG Volume (US lab)	Peak Momentum Req'ts (N-M-S)	Fuel Req't - lbs. (45 day reboost)
Baseline –no Orbiter	–0.3, –7.6, 0.7	50%	2100	1550
Baseline – 1 Orbiter	–14.5, 42.8, –0.5	50%	3300	2650
Option 5 – 1 Orbiter (add'l extended node)	19.0, –37.5, –2.0	50%	7400	2650
Option 6 – 1 Orbiter (logistics module)	13.5, –30.8, 1.7	50%	4500	2550
Option 5 – 2 Orbiters (add'l extended node)	3.3, –23.3, 24.4	N/A	5700	N/A
Option 6 – 2 Orbiters (logistics module)	–0.3, –4.0, 9.0	N/A	4600	N/A

PMC Mass Property Results

The facing page summarizes in tabular form the results obtained for the PMC options studied. Mass properties determined include mass, center of mass, inertia, and ballistic coefficient. Single orbiter configurations examined included the baseline configuration, as well as options 5 and 6. Likewise, options 5 and 6 were analyzed with two orbiters attached.

Orbiter Utilization as an ACRV

PMC MASS PROPERTY RESULTS

Configuration	Mass (Kg)	Ballistic Coefficient (Kg/met**2)	Center of Mass (met) X Y Z	Inertia * 10^6 (Kg–met**2)
Baseline –no Orbiter	166,500	56.5	1.4, 0.7, 3.4	63, 9.3, 67 –0.3, –0.3, –0.6
Baseline – 1 Orbiter	273,500	60.5	8.2, –0.8, 8.3	86, 49, 88, –4.7, 14.9, –3.8
Option 5 – 1 Orbiter (add'l extended node)	282,000	60.6	8.3, 4.3, –0.1	86, 45, 93, 10, –11, –6
Option 6 – 1 Orbiter (logistics module)	274,600	63.7	–5.4, –0.8, 9.0	79, 52, 98, 4, –17, –4
Option 5 – 2 Orbiters (add'l extended node)	389,000	73.0	11.2, 2.2, 4.3	120, 84, 107, 4, 2, –15
Option 6 – 2 Orbiters (logistics module)	381,500	95.3	1.4, –1.5, 10.9	93, 110, 144 –0.3, –3, –5

Assembly Complete Analysis Results

The facing page summarizes in tabular form the results obtained for the AC options studied. Only options which could accommodate two orbiters simultaneously were analyzed. Flight characteristics summarized include Torque Equilibrium Attitude (TEA) given in a yaw, pitch, and roll sequence (expressed in degrees): the percent of the steady state one μG volume existing in the pressurized US and international lab modules; the peak momentum requirements to maintain the TEA using CMGs (expressed in Newton–meter–seconds); and the fuel reboost requirements (expressed in pounds), consistent with the 45 day reboost assumptions stated earlier. Single attached orbiter configurations examined included the baseline configuration, as well as options 5, 6, 7, and 8. Likewise, the TEA and peak momentum requirements for options 5, 6, and 7 were analyzed with two orbiters attached.

Clearly the superior configuration from a microgravity, TEA, and momentum requirements point of view was the new hardware *oblique* docking mechanism option 8. Option 8 also appeared superior from certain operational aspects as well.

All single orbiter reboost fuel requirements were approximately 35% higher than the baseline AC without the attached ACRV orbiter.

Orbiter Utilization as an ACRV

ASSEMBLY COMPLETE ANALYSIS RESULTS

Configuration	TEA (deg)	Percent 1 μG Volume (US lab, total)	Peak Momentum Req'ts (N-M-S)	Fuel Req't – lbs. (45 day reboost)
Baseline –no Orbiter	0.3, –7.5, 0.4	40% 80%	5000	4600
Baseline – 1 Orbiter	–3.7, 31.2, 0.7	60% 20%	5000	6300
Option 5 – 1 Orbiter (add'l extended node)	8.9, –25.5, 0.0	35% 25%	6200	6400
Option 6 – 1 Orbiter (logistics module)	–7.1, –12.0, 0.3	40% 65%	9400	6200
Option 7 – 1 Orbiter (ESA module)	2.8, –30.4, 0.8	40% 20%	7600	6200
Option 8: Oblique Orbiter	***–4.3, –0.2, 0.6***	**85% 85%**	***3900***	***6125***
Option 5 – 2 Orbiters	4.3, 14.7, 8.3	N/A	6000	N/A
Option 6 – 2 Orbiters	32.3, 1.7, 1.0	N/A	8300	N/A
Option 7 – 2 Orbiters	–0.7, –0.6, 3.1	N/A	8500	N/A

AC Mass Property Results

The facing page summarizes in tabular form the results obtained for the AC options studied. Mass properties determined include mass, center of mass, inertia, and ballistic coefficient. Single orbiter configurations examined included the baseline configuration, as well as options 5, 6, 7 and 8. Likewise, options 5, 6, and 7 were analyzed with two orbiters attached.

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Orbiter Utilization as an ACRV

ASSEMBLY COMPLETE MASS PROPERTY RESULTS

Configuration	Mass (Kg)	Ballistic Coefficient (Kg/met**2)	Center of Mass (met) X Y Z	Inertia * 10^6 (Kg-met**2)
Baseline –no Orbiter	265,100	50.1	–1.2, 0.2, 3.4	155, 22, 168, 0.5,–1.3,–1.0
Baseline – 1 Orbiter	372,000	55.5	4.5, –0.7, 6.9	183, 75, 203, –5, 20, –4
Option 5 – 1 Orbiter (add'l extended node)	379,500	55.7	4.7, 3.1, 0.7	183, 70, 210, 15, –15, –7
Option 6 – 1 Orbiter (logistics module)	379,800	63.3	–10.8, 1.1, 5.5	165, 116, 261, –6, –21, 0.7
Option 7 – 1 Orbiter (ESA module)	372,000	58.6	–5.4, –0.8, 7.4	177, 64, 198, 4.5, –18,–4.8
Option 8: Oblique Orbiter	***372,000***	***66.0***	***6.2, –0.7, 4.0***	***162, 82, 231, –6, 0.1, –1.6***
Option 5 – 2 Orbiters	486,400	65.6	7.8, 1.7, 4.1	216, 116, 231, 8, 3.7, –15
Option 6 – 2 Orbiters	486,700	68.0	–4.3, 0.2, 7.8	186, 208, 337, –17, 5.6, –3
Option 7 – 2 Orbiters	479,000	77.6	–0.1, –1.3, 9.3	193, 129, 249, –0.5, 0,–6.5

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rescue_results

Summary

Geometric inspection revealed that the baseline configurations studied (both PMC and AC) cannot accommodate two orbiters simultaneously. The second docking mast merely serves as an alternate attach location for one orbiter. Certain modified hardware options studied also could not accommodate dual simultaneous docking. These included the use of an additional standard resource node, and the use of extended resource nodes, independent of the attitude of the second attached orbiter. Docking a second orbiter to the end port of one of the resource nodes provided minimal physical clearance but presented significant operational problems. An additional extended node was required to achieve a three foot clearance from a second orbiter on the front of the station, and then, only in a tail-up attitude. Other modified options that were viable from a clearance point of view included locating the ACRV orbiter off the front nodes, or on the logistics or ESA modules, for example. All of the resulting feasible modified hardware configurations exhibited large torque equilibrium attitudes which had an adverse impact on pointing and microgravity.

The presence of an attached orbiter increases reboost fuel requirements (70% for PMC; 35% for AC) by virtue of the increased mass. Attitude control sizing requirements were only modestly impacted for the ACRV orbiter locations considered in this study.

Orbiter Utilization as an ACRV

SUMMARY

- The *baseline* station cannot simultaneously accommodate two Orbiters.

- Certain *modified* hardware approaches can accommodate a second Orbiter. **The presence of any docked Orbiter significantly alters the mass properties of *Freedom*, resulting in :**
  - Large torque equilibrium attitudes
    - adverse impact on pointing
    - rotates desirable micro-g environment out of pressurized volume
  - Large reboost fuel increase
    - approximately 70% for PMC
    - approximately 35% for AC

- Modest increase in CMG attitude control sizing caused by the presence of the ACRV Orbiter not significant for the locations considered in this study.

Summary (Continued)

The utilization of an oblique docking mechanism essentially allowed the orbiter to be used as *ballast*, adjusting the mass distribution such that a desirable TEA, and hence, pointing and microgravity environment were achieved. It was noted however that the oblique mechanism is *configuration* dependent, that is, different optimal oblique angles were required for different configurations. This implies that either 1) one oblique mechanism could be designed to be optimal in an *average* sense, or tailored for one critical configuration, or 2) the mechanism could be *hinged* to accommodate differing configurations.

The presence of an oblique docking mechanism, while modifying mass properties to achieve acceptable TEA, μG, etc., does not alleviate the reboost fuel penalty associated with the additional mass of the attached orbiter. In additional, the presence of a front node oblique docking mechanism still does not allow for two orbiters on *front* nodes simultaneously.

Orbiter Utilization as an ACRV

SUMMARY (continued)

- Utilization of an *oblique* Orbiter docking mechanism allows torque equilibrium attitudes within $\pm$ 5 degrees of LVLH (improves micro-g, pointing, and controllability). However,
  - Oblique mechanism is *configuration* dependent
  - Does not alleviate increased reboost fuel requirements
  - Still cannot accommodate two Orbiters on *front* nodes simultaneously

Qualitative Assessment Summary

For each of the feasible candidate ACRV orbiter locations studied, a qualitative assessment was made of the following station operation related issues: 1) Docking and Proximity Operations, 2) Clearances, 3) Payload Viewing Interference, and 4) Station Radiator Blockage.

The baseline location on the forward port node was judged to have no problems with any of the 4 issues listed (which is why this location is nominal).

Both options 2 (ACRV orbiter on the end port of the port resource node) had severe docking and prox ops problems involving off nominal approach paths and potential interference with rotating solar arrays. The tail–down attitude of option 2–A had small clearances between the payload bay doors of the ACRV orbiter, and the wings of the nominal orbiter. Option 2–B clearance was somewhat better (ACRV orbiter tail–up). However, option 2–B appeared to significantly reduce viewing capability in the zenith direction (option 2–A had the same problem for nadir viewing). As the ACRV orbiter is located on a forward node, the options 2 had no station radiator blockage problem.

Option 5, with the ACRV orbiter located facing forward, tail–up, on an extended, additional starboard node had no radiator blockage problems, but potential docking and clearance problems (only about 3 feet clearance between payload bay doors for dual simultaneous docked orbiters was observed). In addition, option 5 reduced the zenith field of view.

Option 6, with the ACRV orbiter attached to the modified logistics module, required an Rbar docking approach path. However, ample clearance seemed to be available. But with the ACRV orbiter located in a nose–forward attitude, nadir viewing was significantly compromised, and the ACRV orbiter appeared to block the station radiated heat path.

Option 7, with the ACRV orbiter attached to a node underneath the modified ESA lab in a nose–forward attitude, also required an Rbar docking approach path and offered little clearance with the JEM module. Nadir viewing was severely compromised for the international modules. Only partial station radiator blockage was observed compared to the logistics module option 5 since the ACRV orbiter is somewhat aft of the station radiator.

Option 8 , the new hardware oblique docking module concept, had no apparent problems with the above four operations related issues.

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Qualitative Assessment Summary

Candidate ACRV Orbiter Location[1]	Docking and Prox Ops	Clearance	Payload Viewing Interference	Freedom Radiator Blockage
BASELINE Nominal - Port Node (forward, tail down)	●	●	●	●
OPTION 2A Starboard Node (end port, tail down)	■	■	■ (nadir viewing)	●
OPTION 2B Starboard Node (end port, tail up)	■	○	■ (zenith viewing)	●
OPTION 5 Add'l Stbd Extended Node (forward, tail up)	○	○	■ (zenith viewing)	●
OPTION 6 Logistics Module (nose forward)	○	●	■ (nadir viewing)	■
OPTION 7 ESA (node forward)	○	○	■ (nadir viewing)	○
OPTION 8 Oblique Docking Mechanism Port Node	●	●	●	●

[1] those which can accommodate two attached orbiters simultaneously

● no problem ○ slight or potential problem ■ severe or significant problem

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Unresolved Issues

During the course of this preliminary study, a number of questions and issues were raised which require further investigation prior to utilization of a shuttle orbiter as an ACRV. For example, orbiter–to–orbiter, and orbiter–to–station acceptable clearance specifications to insure safe rendezvous and docking procedures would need to be defined. The overall question of resource flow from station to ACRV orbiter must be addressed in greater detail. A decision must be made on whether the ACRV orbiter would remain attached to the station at the rendezvous location, or relocated to a 'preferred' attach point. The requirement for Rbar vs Vbar approaches was noted but not evaluated from a propellant or crew training point of view. A more detailed study of the impact of the docked ACRV orbiter on payload viewing, on station heat rejection capacity, and plume impingement impacts should be performed. The new hardware approach utilizing an oblique docking mechanism should be assessed for feasibility and costed, both for a fixed angle as well as an adjustable, hinged mechanism. The issue of ACRV orbiter heat load rejection capability while permanently attached to the station must be studied. Because extended crew on–orbit time intervals could precede an ACRV evacuation, automated landing capability must be demonstrated prior to orbiter ACRV utilization.

Orbiter Utilization as an ACRV

UNRESOLVED ISSUES

- Orbiter-to-Orbiter and ACRV Orbiter-to-station clearance requirements
- Resource transfer flow from station to Orbiter
- Will the ACRV Orbiter be relocated to the same position on *Freedom* following departure of the returning Orbiter?
- Vbar vs Rbar approach and proximity operations noted but not evaluated.
- Docked ACRV Orbiter impact on
  - Payload viewing
  - Station heat rejection capacity
- Plume impingement impacts
- Modified hardware and oblique docking mechanism costs and feasibility
- ACRV Orbiter thermal loads while attached to station
- Automated landing capability

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15. Supplementary Notes

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16. Abstract

Assuming that a Shuttle Orbiter could be qualified to serve long duration missions attached to Space Station Freedom in the capacity as an Assured Crew Return Vehicle (ACRV), a study was conducted to identify and examine candidate attach locations. Baseline, modified hardware, and new hardware design configurations were considered. Dual simultaneous Orbiter docking accommodations were required. Resulting flight characteristics analyzed included torque equilibrium attitude (TEA), microgravity environment, attitude controllability, and reboost fuel requirements. The baseline Station could not accommodate two Orbiters. Modified hardware configurations analyzed had large TEA's. The utilization of an oblique docking mechanism best accommodated an Orbiter as an ACRV.

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